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## SHORT COMMUNICATION

# The deliberate introduction to Australia of the shrub genus *Pentzia* (Asteraceae) and its subsequent persistence and spread

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***Abstract***: *Pentzia* is a predominantly southern African genus of low shrubs, many of which are important fodder plants for sheep in semi-arid and arid areas. Attempts since 1869 to introduce *Pentzia incana* to south-eastern Australia for sheep fodder are described. One of these, near Koonamore in north-eastern South Australia, was temporarily successful there and may have led to the only extant stands in Australia – two well-established populations at Mount Serle in the northern Flinders Ranges. These events are related to the biology of the species and to similar events concerning the deliberate introduction of the species to Arizona. These data are discussed in terms of current ideas about plant introduction, dispersal, invasion and the concept of sleeper weeds.

*Pentzia globosa* is currently known from a single stand in Australia, at Bundaleer Forest in the Mid North of South Australia. The history of this occurrence is briefly discussed.

For both species, it is concluded that regular monitoring is needed in case of rapid spread and that further data are needed on the extent to which they exhibit weedy behaviour in southern Africa.

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## Introduction

The genus *Pentzia* (Asteraceae) comprises ± 27 species of highly aromatic low shrubs mostly native to southern Africa but with three species in North Africa and one in Yemen. Many are important fodder plants in arid areas, especially for sheep (Magee & Tilney 2012).

The species of *Pentzia* introduced to Australia are *Pentzia globosa* Less. and *Pentzia incana* (Thunb.) Kuntze (in both cases introduced to New South Wales and South Australia; Thompson 2007); the latter species at least is an important forage plant for sheep in winter rainfall areas of southern Africa (Milton *et al*. 1999). In the late 1920s and early 1930s in an arid part of South Australia, *Pentzia incana* was part of an unusual and neglected project to introduce exotic perennial plants to areas where overgrazing by stock had eliminated the native vegetation, so that such areas could be revegetated and soil drifting prevented (Ratcliffe 1936).

The aim of the present paper is to relate what is known of this project, to describe the subsequent spread of *Pentzia*

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*incana* in Australia and to examine what contribution the story makes to current ideas about plant introduction, dispersal and invasion. Remarkably, at much the same time as the Australian project and for the same reasons, the US Soil Conservation Service introduced *Pentzia incana* to sites in Arizona from which it subsequently spread (Keil 2006). These events are also described. Finally, the history of *Pentzia globosa* in Australia is briefly related.

## The Species

Both *Pentzia incana* and *Pentzia globosa* are low, compact shrubs to 60cm high with small leaves to 15mm long and yellow corollas. In *Pentzia incana* (Fig. 1), the younger stems and leaves are white- to grey-tomentose, so the leaves are greyish, while in *Pentzia globosa* the leaves are ± glabrous and so are green. The pappus is a corona c.1mm long in *Pentzia incana* and 0.3mm long in *Pentzia globosa*. The fruits of *Pentzia incana* secrete mucilage when wetted (Thompson 2007, Magee & Tilney 2012); this is true of the whole genus (Oberprieler *et al*. 2007). *Pentzia incana* is known both as Karoo Bush (Ratcliffe 1936) and African Sheep Bush (Thompson 2007). In South Africa, *Pentzia incana* has been described as a palatable generalist (Pienaar *et al*. 2004). Overgrazing by stock leads to it, and other karoo shrubs, replacing native grassland over wide areas (Darkoh 2001).

The approximate mean annual rainfall ranges in South Africa are 160–260mm for *Pentzia globosa* and 170–260mm for *Pentzia incana* (Palmer & Hoffman 1997). *Pentzia incana* flowers opportunistically in response to rainfall and can root where branches touch the soil, leading to clonal spread (Esler 1999).

In the 1920s and 1930s, it was common to treat *Pentzia incana* as one of a drought-adapted growth form called 'tomentose microphylls', being shrubs having shoots covered with a dense tomentum and with small leaves. The group includes other composites like *Artemisia* spp. (the sagebrushes) of North America, North Africa etc. but also the chenopods *Atriplex, Einadia, Maireana* and *Rhagodia* (Wood 1924, Trumble 1932).

*Pentzia globosa* has been listed as a weed in South Africa, while *Pentzia incana* has been listed as a weed both there and in Australia and USA (Randall 2002).

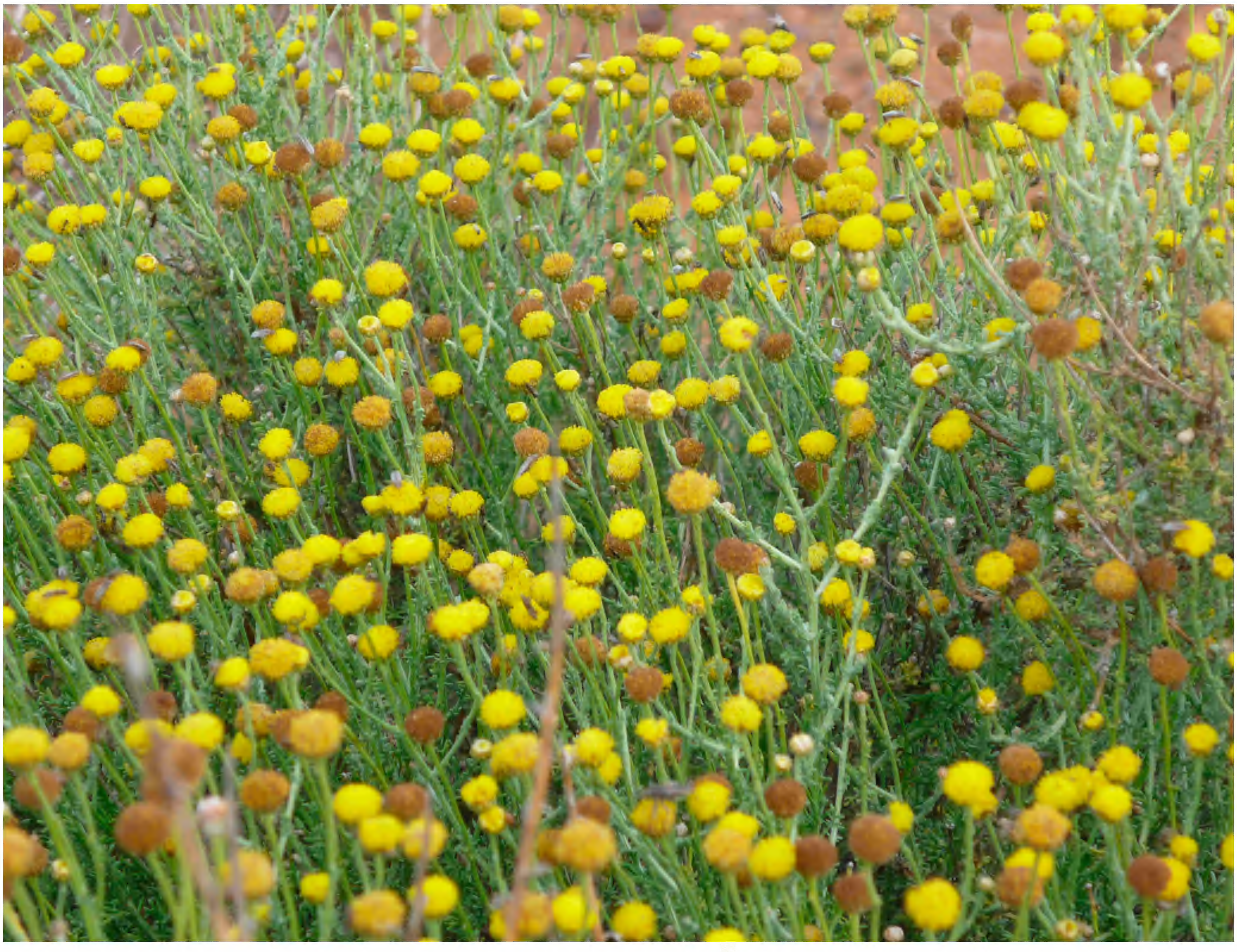

**Fig. 1.** *Pentzia incana* near Mount Serle homestead, northern Flinders Ranges, 20 April 2012.

## The Early Records of *Pentzia incana* in Australia

In about 1869, the Adelaide Botanic Garden received seeds of *Pentzia incana* (as '*Pentia virgata*') from Dr. Hooker of the Royal Botanic Gardens, Kew (Schomburgk 1872, Kloot 1986). The species was thought to be 'a most valuable sheep fodder' and the plants grew vigorously in Adelaide for at least two years without being watered. In 1871, plants propagated from cuttings were offered to landholders (Schomburgk 1872). A few plants were being grown in the Murray Mallee near Lyrup in 1897 (Anonymous 1897) and near Port Lincoln in 1900 where it was considered 'much too slow of growth to be profitable' (Anonymous 1900).

There are two further records in the period before the trial introduction in 1930; an 1885 record without details from the Queensland nursery trade (Ingram 2008) and a single collection from Nyngan in central west New South Wales in November 1913 (J.H. Maiden s.n. NSW; see Thompson 2007).

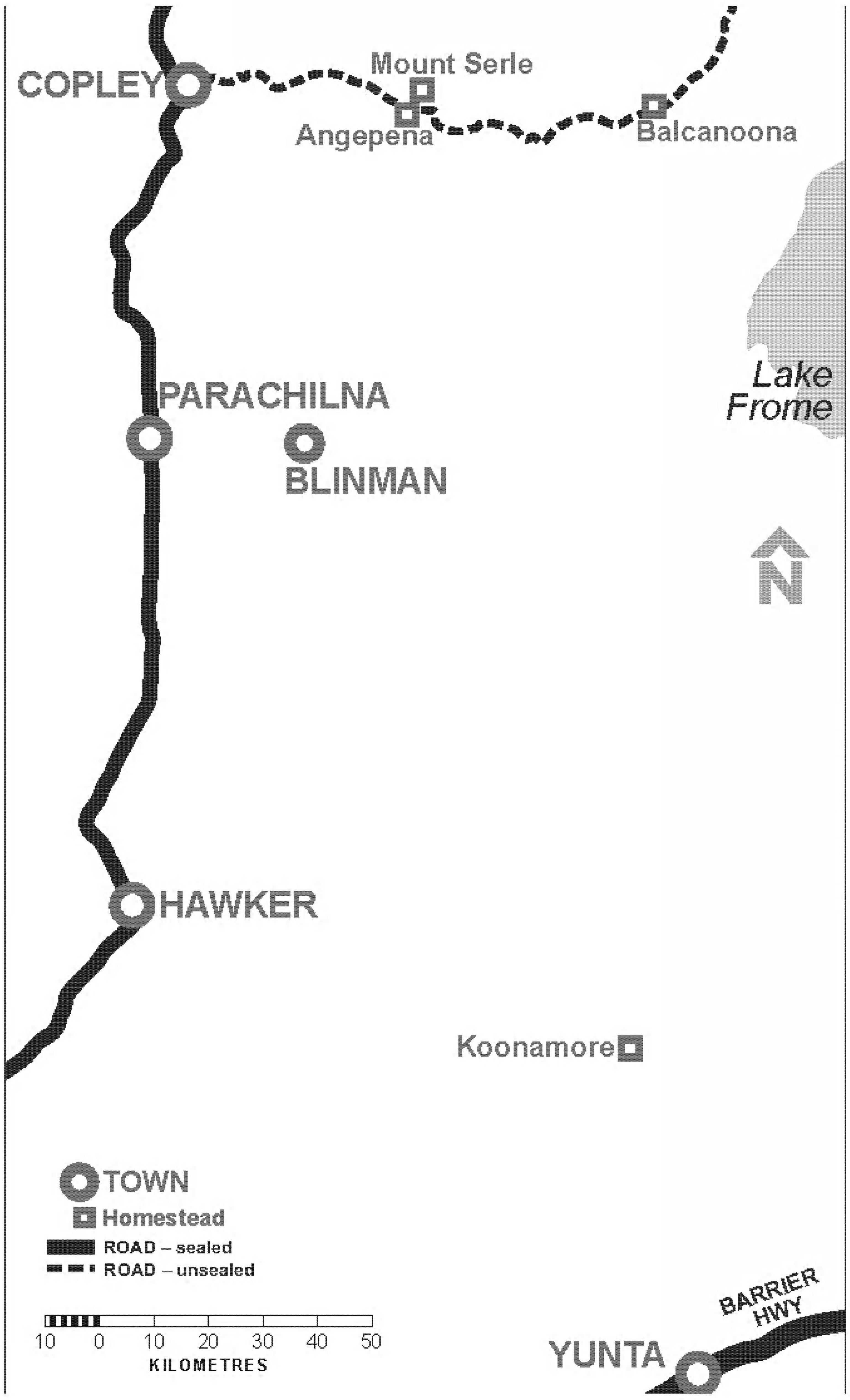

**Fig. 2.** Part of north-eastern South Australia showing the location of the main place names mentioned in the text.

Later in this paper, the possible spread of *Pentzia incana* from its 1930 introduction site will be discussed. Given the foregoing, the possibility must be kept in mind that some populations may have resulted from planting by landholders rather than unassisted seed dispersal from the 1930 introduction site.

## The Introduction Trial of *Pentzia incana* in South Australia

In 1912 T.G.B. Osborn was appointed first professor of botany at the University of Adelaide. By the 1920s, he became concerned about widespread overgrazing and soil erosion in the arid-zone (Robertson 1988) and in 1925 established the Koonamore Vegetation Reserve, now called the TGB Osborn Vegetation Reserve (OVR), to study recovery of overgrazed arid-zone vegetation (Sinclair 2005).

In 1927, Osborn co-opted T.B. Paltridge and J.G. Wood to establish experimental plots at OVR (Specht 2002); one experiment was a seed sowing trial to test whether certain exotic species could be established in that part of the arid zone (Ratcliffe 1936, Table 1). By that time, Wood was fully aware that *Pentzia incana* was important and dominant in similar climates in the Upper Karoo, South Africa (Wood 1924); it was included in the trial (Ratcliffe 1936).

Of the five species listed as included in the trial (Table 1), *Pentzia incana* is the only one known to have flowered, set seed and produced a second crop of seedlings (Ratcliffe 1936). The only other details known are that the *Pentzia incana* seeds were sown into boxes on 16 July 1930, transplanted on 22 October 1930 (University of Adelaide Archives 1930) and that all plants died during drought in early 1934 (Ratcliffe 1936).

After that, nothing is known of *Pentzia incana* at OVR until, in August 1971, M.D.Crisp found a single plant just outside the 'plant introduction quadrat' at OVR (CBG; Crisp 307). This or a nearby plant was re-collected in October 1973 (AD; Crisp 656; Crisp pers. comm.). While *Pentzia incana* has not been the subject of a general, systematic search, the area in and around the OVR plant introduction plot has been inspected annually since 1980 without it being found (R. Sinclair pers. comm.).

Aside from the records from OVR, since the 1930s there are only two areas in Australia where *Pentzia incana* has been recorded as naturalized, both in the northern Flinders Ranges (Fig. 2). Firstly, in November 1964, *Pentzia incana* was collected near Angepena homestead (AD; Lothian 3242). I searched the location without success on 20 April 2012. Secondly, *Pentzia incana* was collected a few km away from this site near Mount Serle homestead in April 1977 (AD; Williams 9258) from where it was re-collected in November 1989 (NSW; Nordenstam 996). Then, in December 2011, a large stand was found about one km from the site of the 1977 record (AD; Brewer 646). Brewer recorded about 300 plants there, but, in April 2012, with more time for searching, I estimated at least 1000 plants over an area of 40m x 150m.

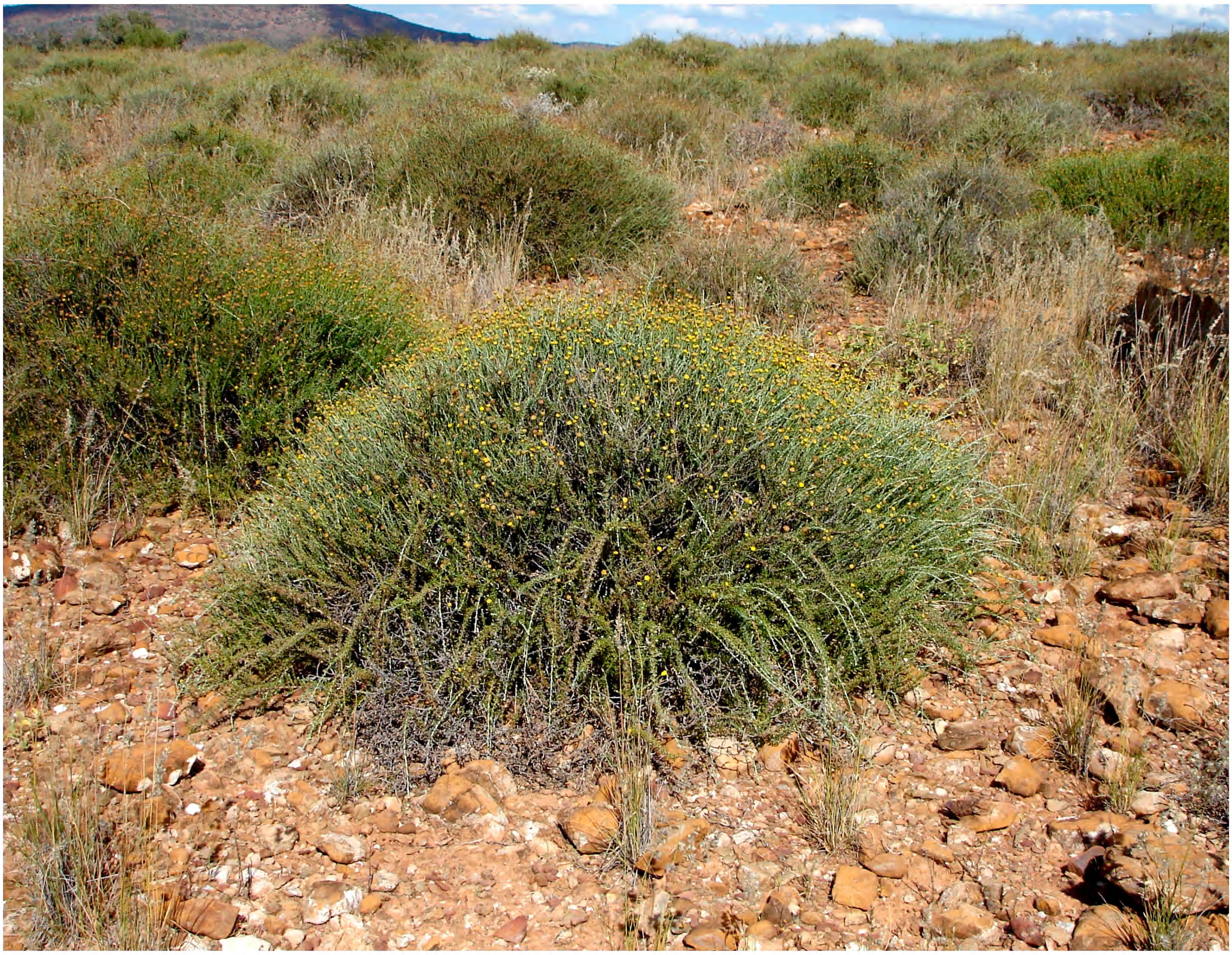

**Fig. 3.** Low shrubland dominated by *Pentzia incana* up to 40 cm high on stony soils near Mount Serle homestead, 20 April 2012.

**Table 1. The results of sowing seeds of exotic perennial plants at OVR; most or all trials held in 1930.**

| **Family/species** | **Common name** | **Origin** | **Result of seed sowing** | **Reference** |
|---|---|---|---|---|
| Asteraceae | | | | |
| *Parthenium argentatum* L. | Guayule | N. America | Seed germinated.<br>Seedling fate unknown | Archives* |
| *Pentzia incana* (Thunb.) Kuntze (as *Pentzia virgata*) | African sheep bush | S. Africa | Seed germinated.<br>Seedlings matured.<br>One crop of seed produced | Ratcliffe 1936 |
| Leguminosae | | | | |
| *Parkinsonia* sp. (probably *Parkinsonia aculeata* L.) | Jerusalem thorn | N.and S. America | Failed to germinate | Ratcliffe 1936 |
| *Trigonella foenum-graecum* L. | Fenugreek | Mediterranean | Seed planted.<br>Fate unknown | Archives* |
| Zygophyllaceae | | | | |
| *Larrea* sp. (as *Covillea* sp.) | Possibly creosote bush | N. America | Failed to germinate | Ratcliffe 1936 |

*University of Adelaide Archives; see References

*Pentzia incana* is the dominant shrub in this area (Figs. 3 and 4), which is surrounded by grassland dominated by *Enneapogon* sp. Also, I found a further stand, of about 500 plants, 1.7 km away along 200 m of track (AD; Parsons 704).

These records in the Angepena/Mount Serle area are about 180 km from the records at OVR.

## *Pentzia incana* in the Australian Capital Territory

In the late 1920s and the 1930s, the CSIR Division of Plant Industry in Canberra included a Plant Introduction Section which imported and assessed exotic plants of possible economic use. Seeds of *Pentzia incana* (as *Pentzia virgata*) were received in May 1929 from E.J. Dunn of Kew, Victoria (CPI no. 1355, McTaggart & Hartley 1931) and in February 1931 from W.V. Blewett of Imperial Chemicals Industries, Melbourne (CPI no. 2033, McTaggart & Hartley 1932). The notes for the latter state that 'it is a very valuable stock feed on the dry Karoo of South Africa.' Nothing further is known of *Pentzia incana* in the ACT except that there are CANB collections of it by A. Melvaine from 'CSIR plots, Black Mountain, Canberra' from November 1938 and August 1939. These are obviously the basis for the fact that Australia's Virtual Herbarium, the Atlas of Living Australia and New South Wales Flora Online record *Pentzia incana* as being naturalized in the ACT (all accessed on 5 March 2012). Clearly, these records should be deleted.

## *Pentzia incana* in Central Australia

In Alice Springs from 1956 to 1962, the Division of Plant Industry, CSIRO conducted trials to find exotic plant species which could be used to make native pastures more productive. In the initial trials, seeds were sown in irrigated plots. Nine shrub species from the Karoo region of South Africa, including *Pentzia incana*, established satisfactorily at this stage (Winkworth & Hodder 1962). No further details are available on the fate of these species except that the South African composite *Osteospermum muricatum* E. Mey. ex DC. was collected four times as a naturalized weed in Central Australia between 1974 and the early 1980s, but has not been collected or seen since (Albrecht & Pitts 2004).

## *Pentzia incana* in North America

*Pentzia incana* was introduced to Arizona by the US Soil Conservation Service in the 1930s (Howery 2009) for erosion control and range improvement (Pierson & McAuliffe 1995). It is not known how many plantings were made, but at least one was as recent as 1946 (Munda & Pater 2003).

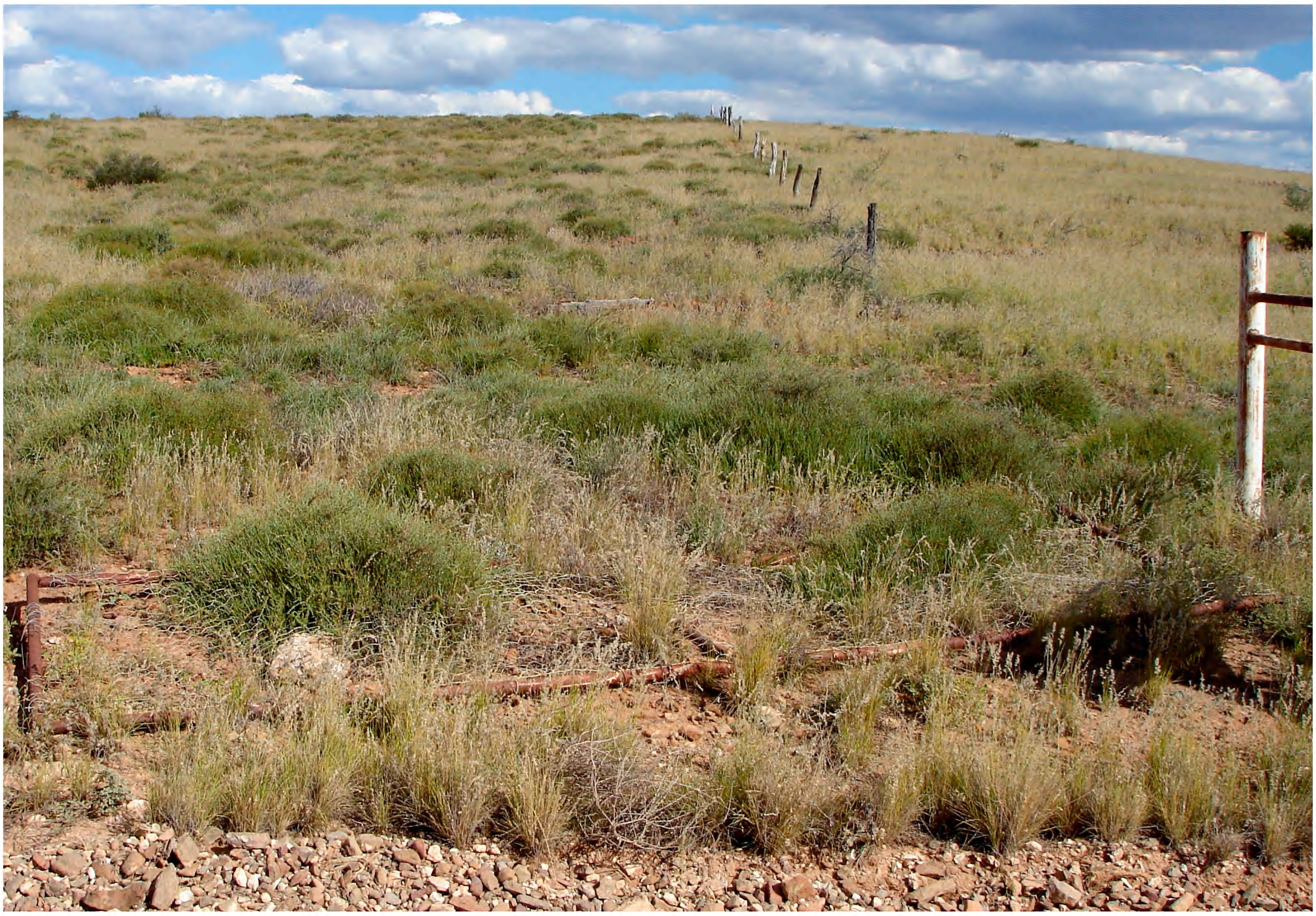

**Fig. 4.** Low shrubland of *Pentzia incana* extending for 150 m from a track up to the horizon on a hillslope near Mount Serle homestead, 20 April 2012. Note the absence of *Pentzia incana* on the right side of the fenceline at right. The grazing history at the site is not known.

In 1993, *Pentzia incana* was recorded for the first time from New Mexico (Spellenberg *et al.* 1993) at a distance of 312 km from the nearest stand in Arizona. By 2012, 11 stands were known in Arizona and two in New Mexico (http://intermountainbiota.org/portal/taxa/index.php?taxon=2331, accessed 4 Feb 2012).

The North American literature treats *Pentzia incana* as an invasive weed (Howery 2009), with evidence of it 'tending to seed itself' and successfully establishing seedlings (Spellenberg *et al.* 1993). There is no reference to it being used as a garden plant.

## The introduction of *Pentzia globosa* to Australia

*Pentzia globosa* is known for Australia from only four collections. In 1894, it was collected from Gosford on the New South Wales central coast by an unknown collector. Then, in 1897 it was collected from Bundaleer Forest near Jamestown in the Mid-North of South Australia. A big population was found from the same general location in 1988 (AD; Bates 14272; Thompson 2007). Finally, 1000 plants were recorded from Bundaleer Forest in December 2011 (AD; Brewer 625). The 1988 stand occurred 100 m away from the 2011 one (Bates pers. comm.); both were from plantations of Sugar Gum (*Eucalyptus cladocalyx* F. Muell.).

Bundaleer Forest, where *Pentzia globosa* was recorded as early as 1897, was the first government forest plantation in Australia; planting commenced there in 1876 (Robinson 1971). Dr. R. Schomburgk, the Director of the Adelaide Botanic Gardens, was involved in choosing the tree species (Robinson 1971). It is not known if any shrubs were planted, but Schomburgk had begun propagating *Pentzia incana* at Adelaide in about 1870 (Schomburgk 1872), making it conceivable that *Pentzia globosa* was a deliberate introduction at Bundaleer.

The mean annual rainfall at Jamestown near Bundaleer Forest is 367 mm; a lot higher than the 160–260 mm range for *Pentzia globosa* in South Africa (Palmer & Hoffman 1997).

There is a single record, without details, of *Pentzia globosa* from the Australian nursery trade; from South Australia in 2005 (Ingram 2008).

In summary, at present *Pentzia globosa* is known in Australia from a single population in an area where it has been present, at least intermittently, for a minimum of 115 years. Information is needed on the extent to which it exhibits weedy behaviour in southern Africa; also it should be regularly monitored at Bundaleer Forest in case it begins to spread.

## Concluding discussion

Because of the stress imposed by low rainfall, it has been assumed that few introduced plant species are capable of invading arid and semi-arid areas. However, in the case of the arid southwestern United States, Pierson and McAuliffe (1995) have suggested that this may be dangerously inaccurate. There, 15 species deliberately introduced to Arizona by the Soil Conservation Service before 1942 have become widely established. These include the South African shrubby composites *Pentzia incana* and *Euryops multifidus* DC., the latter having become a very serious weed forming virtually uninterrupted monocultures, suppressing native species and causing marked increases in soil erosion (Pierson & McAuliffe 1995).

The northern South Australia/Central Australia area has a similar climate to Arizona. Both areas are arid, with biseasonal rainfall showing significant peaks in winter and summer and both carry plant species whose main growth periods are either in winter or summer (Slatyer 1962, Pierson and McAuliffe 1995). However, it is hard to find Central Australian data to compare with the Arizonan data above. Certainly, the deliberately introduced *Cenchrus ciliaris* L. (Buffel Grass) has become a very serious weed of native vegetation in both areas (Marshall *et al.* 2012). The (temporary?) naturalization of the South African shrubby composite *Osteospermum muricatum* around Alice Springs is dealt with earlier. The finding that, of 72 species nominated as Australian Weeds of National Significance, only 3 are restricted to inland arid and semiarid environments, and other data in the paper (O'Donnell *et al*, 2012), suggest that the weed situation in and around Central Australia is not yet as serious as in Arizona.

It is against this background that we need to assess the potential of *Pentzia incana* to become a problem in southern Australia. It is now more than 80 years since *Pentzia incana* was deliberately introduced at OVR, but it has yet to become widely successful. It is clearly not the weed type that spreads rapidly soon after introduction (e.g. *Mimosa pigra* L. in Thailand, Groves 2006). It could be an example of the lag phase phenomenon whereby alien species are present in low numbers for a long time before an explosion in abundance occurs (Lenda *et al.* 2012). Where the lag period is more than 50 years, as in the present case, such species are called sleeper weeds (Groves 2006).

Unfortunately, we lack the data to accurately assess the extent to which *Pentzia incana* is capable of weedy behaviour. To summarize what little we know, firstly for fruit dispersal, the genus *Pentzia* lacks a parachute-type pappus; it has no special adaptations for wind dispersal. However, because the achenes are only 1–1.5 mm long (Thompson 2007), it is clear that they might be moved substantial distances by wind. Also, the fruits secrete mucilage when wetted (Magee & Tilney 2012); this suggests the possibility of long distance dispersal by adhesion to vertebrates, including intercontinental dispersal by birds, as it does in other species (Franzke *et al.* 2011). Such dispersal may be reflected in the 312 km disjunction involved in the establishment of *Pentzia incana* in New Mexico from the source area in Arizona (see earlier) and in the 180 km disjunction of the Mount Serle *Pentzia incana* stand from the parent OVR stand (if planting by landholders was not involved).

Turning to behaviour other than dispersal, the *Pentzia incana* plants at Mount Serle were flowering and fruiting abundantly (pers. obs.) and the North American data document successful seedling establishment (Spellenberg *et al.* 1993).

Regarding other traits important for weediness (Pheloung *et al*. 1999), we do not know if *Pentzia incana* can self-fertilize, or form a persistent seed bank. However, it is capable of vegetative propagation (Esler 1999). It is also capable of becoming co-dominant over large areas in South Africa (Milton *et al*. 1999) and dominant over smaller ones as at Mount Serle (pers. obs.).

Perhaps the most striking feature of the behaviour of *Pentzia incana* in Australia is the way it re-appeared at OVR after an apparent absence of 37 years. Persistence is also shown by the fact that it has now been present, perhaps intermittently, in the Angepena-Mount Serle area for a minimum of 48 years.

Regarding the weediness trait 'number of introductions outside the natural range of the species' (Pheloung *et al*. 1999), we have the 13 populations in and near Arizona, (an unknown number of them from deliberate plantings), and, at present in Australia, the two sub-populations at Mount Serle. The mean annual rainfall (mar) in the Mount Serle area is about 250 mm. Droughts there may limit *Pentzia incana* expansion given that, in South Africa, 78% of *Pentzia incana* plants died when only 70 mm of rain fell in a year in an area of 269 mm mar (Milton *et al*. 1999). Nevertheless, the presence of sizeable patches dominated by *Pentzia incana* at Mount Serle suggests that regular monitoring is desirable there in case rapid spread occurs. In terms of the definition of sleeper weeds (Groves 2006), *Pentzia incana* has already fulfilled the 50 year lag period criterion; it remains to be seen whether it fulfils the other criterion by becoming seriously invasive.

Finally, there is the question of the possible usefulness of *Pentzia incana*. When I asked for information about *Pentzia incana* in 'Across the Outback', a newsletter for pastoralists in northern South Australia, the only response was on behalf of a New South Wales grazier formerly from South Africa pointing out its value as sheep fodder there and hoping to trial it here. Thus, there is still interest in this topic so many years after the preliminary trials in South Australia in 1869 to 1900 and in 1930, as well as in the Australian Capital Territory (1929–1939) and Central Australia (1956–1962). However, we clearly need more data on the extent of its weediness in South Africa and its adaptability to Australian conditions so that we can assess its usefulness here.

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## References

Albrecht, D.A. & Pitts, B. (2004) *The Vegetation and Plant Species of the Alice Springs Municipality*. Greening Australia: Alice Springs.

Anonymous (1897) Bureau reports. Lyrup, September 7. *Journal of Agriculture and Industry South Australia* 1: 296.

Anonymous (1900) Bureau reports. Port Lincoln, February 16. *Journal of Agriculture and Industry South Australia* 3: 778.

Darkoh, M. (2001) Agriculture and biodiversity in the drylands of Africa. *In*: Wiseman, R. & Hopkins, L. *Sowing the Seeds for Sustainability*, pp. 38–47. IUCN: Gland.

Esler, K.J. (1999) Plant Reproductive Ecology. *In*: Dean, W.R.J. & Milton, S.J. (Eds.) *The Karoo,* pp. 123–144. Cambridge University Press: Cambridge.

Franzke, A., Lysak, M.A. & Al-Shehbaz, I.A. (2011) Cabbage family affairs: the evolutionary history of Brassicaceae. *Trends in Plant Science* 16: 108–116.

Groves, R.H. (2006) Are some weeds sleeping? Some concepts and reasons. *Euphytica* 148: 111–120.

Howery, L.D. (2009) *Non-native, Invasive Plants of Arizona*. University of Arizona: Tucson.

Ingram, R. (2008) Cultivated and introduced plants of Australia dataset. Department of Fishery and Forests: Canberra (unpublished).

Keil, D.J. (2006) *Pentzia. In*: Flora of North America Editorial Committee (Ed.) *Flora of North America*, p. 543. Oxford University Press: New York.

Kloot, P.M. (1986) Checklist of the introduced species naturalised in South Australia. *Department of Agriculture South Australia Technical Paper* No. 14: 1–111.

Lenda, M., Skorka, P. & Knops, J.M.H. (2012) Plant establishment and invasions: an increase in a seed disperser combined with land abandonment causes an invasion of the non-native walnut in Europe. *Proceedings of the Royal Society B* 257: 1491–1497.

Magee, A.R. & Tilney, P.M. (2012) A taxonomic revision of *Pentzia* (Asteraceae, Anthemideae) I: the *Pentzia incana* group in southern Africa. *South African Journal of Botany* 79: 148–158.

Marshall, V.M., Lewis, M.M. & Ostendorf, B. (2012) Buffel grass (*Cenchrus ciliaris*) as an invader and threat to biodiversity in arid environments: a review. *Journal of Arid Environments* 78: 1–12.

McTaggart, A. & Hartley, W. (1931) *Plant Introduction Inventory No. 1.* CSIR: Canberra.

McTaggart, A. & Hartley, W. (1932) *Plant Introduction Inventory No. 2.* CSIR: Canberra.

Milton, S.J., Yeaton, R.I., Dean, W.R.J. & Vlok, J.H.J. (1997) Succulent Karoo. *In*: Cowling, R.M., Richardson, D.M. & Pierce, S.M. (Eds.) *Vegetation of Southern Africa*, pp. 131–158. Cambridge University Press: Cambridge.

Milton, S.J., Davies, R.A.G. & Kerley, G.I.H. (1999) Population Level Dynamics. *In*: Dean, W.R.J. & Milton, S.J. (Eds.) *The Karoo,* pp. 183–207. Cambridge University Press: Cambridge.

Munda, B.D. & Pater, M.J. (2003) Revegetation practices on the Santa Rita Experimental Range. *USDA Forest Service Proceedings* RMRS–P–30: 80–87.

Oberprieler, Ch., Vogt, R. & Watson, L.E. (2007) Compositae. XVI. Tribe Anthemideae. *In*: Kubitzki, K. (Ed.) *The Families and Genera of Vascular Plants*, pp. 342–360. Springer: Berlin.

O'Donnell, J.O., Gallagher, R.V. & Wilson, P.D. (2012) Invasion hotspots for non-native plants in Australia under current and future climates. *Global Change Biology* 18: 617–629.

Palmer, A.R. & Hoffman, M.T. (1997) Nama-karroo. *In*: Cowling, R.M., Richardson, D.M. &Pierce, S.M. (Eds.) *Vegetation of Southern Africa*, pp. 167–179. Cambridge University Press: Cambridge.

Pheloung, P.C., Williams, P.A. & Halloy, S.R. (1999) A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management* 57: 239–251.

Pienaar, E., Esler, K.J. & Mucina, L. (2004) Vegetation of mesas and surrounding plains in the southeastern Nama Karoo, South Africa. *South African Journal of Botany* 70: 540–558.

Pierson, E.A. & McAuliffe, J.R. (1995) Characteristics and consequences of invasion by Sweet Resin Bush into the arid southwestern United States. *In*: USDA (Ed.)

*Biodiversity and Management of the Madrean Archipelago*, pp. 219–224. Tucson: Arizona.

Randall, R.P. (2002) *A Global Compendium of Weeds*. R.G. & F.J. Richardson: Meredith, Victoria.

Ratcliffe, F.N. (1936) Soil drift in the arid pastoral areas of South Australia. *Council for Scientific and Industrial Research Pamphlet* No. 64: 1–84.

Robertson, R. (1988) Osborn, Theodore George Bentley (1887–1973). *Australian Dictionary of Biography* 11: 99–100.

Robinson, N. (1971) *Change on Change*. Investigator Press: Adelaide.

Schomburgk, R. (1872) *Report of Director of Adelaide Botanic Garden, 1871*. Government Printer, Adelaide.

Sinclair, R. (2005) Long-term changes in vegetation, gradual and episodic, on the TGB Osborn Vegetation Reserve, Koonamore, South Australia (1926–2002). *Australian Journal of Botany* 53: 283–296.

Slatyer, R.O. (1962) Part III. Climate of the Alice Springs Area. *In*: Perry, R.A. (Ed.) *General Report on Lands of the Alice Springs Area, Northern Territory*. Land Research Series No. 6, pp. 109–121. CSIRO: Melbourne.

Specht, R. (2002) Wood, Joseph Garnett (1900–1959). *Australian Dictionary of Biography* 16: 578–579.

Spellenberg, R., McIntosh, L. & Brouillet, L. (1993) New records of angiosperms from southern New Mexico. *Phytologia* 75: 224–230.

Thompson, I.R. (2007) A taxonomic treatment of tribe Anthemideae (Asteraceae) in Australia. *Muelleria* 25: 21–58.

Trumble, H.C. (1932) Preliminary investigations on the cultivation of indigenous saltbushes (*Atriplex* spp.) in an area of winter rainfall and summer drought. *CSIR Journal* 5: 152–161.

University of Adelaide Archives: Series 472 Koonamore Vegetation Reserve Logbooks, Vol. 1, 1926–1939.

Winkworth, R.E. & Hodder, R. M. (1962) Plant introduction at Alice Springs to 31st July 1962. *CSIRO Division of Land Research and Regional Survey Technical Memorandum* 62/17.

Wood, J.G. (1924) The relations between distribution, structure and transpiration of arid South Australian plants. *Transactions of the Royal Society of South Australia* 48: 226–235.

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# Using high resolution digital aerial imagery interpreted in a 3-D digital GIS environment to map predefined plant communities in central-southern New South Wales

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***Abstract***: Aerial photo interpretation of high resolution airborne imagery (ADS40) was used in a three-dimensional (3-D) digital Geographic Information System (GIS) environment to map native plant communities defined in the NSW Vegetation Classification and Assessment (NSW VCA) in central-southern New South Wales. NSW VCA plant community types form part of the NSW *BioMetric* vegetation type dataset underpinning NSW natural resource management (NRM) planning frameworks. This region was previously devoid of detailed vegetation mapping. In addition to developing a novel method for mapping plant communities, the use of ADS40 imagery allowed for capture of multiple attributes in each map polygon including attributes pertaining to dominant species and vegetation condition. Such data informs multi-attribute models used in conservation planning, providing utility beyond that of a singular plant community map.

A total of 546,150 hectares of native vegetation in 100 native plant communities was mapped across the study area (Coolamon, Cootamundra, Junee, Lockhart, Narrandera, Tarcutta, Urana, Wagga Wagga and Yanco 1:100,000 mapsheets and Ariah Park, Wallaroobie Range and Yoogali 1:50,000 mapsheets). Exotic pine plantations and native species plantings were also mapped. Remnants of greater than one hectare were captured through on-screen GIS digitising at scales of approximately 1:4,000. The plant community type mapping was independently assessed using random blind validation points as having a user accuracy of 87%. This level of accuracy demonstrates the applicability of the methodology for mapping open forests, woodlands and open woodlands of south-eastern Australia and probably other vegetation elsewhere. Such accurate mapping provides end users with confidence when using vegetation maps in environmental assessment and land use planning.

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## Introduction

Native vegetation maps provide details on the spatial extent of each vegetation type and are widely used to predict ecological values within the landscape. They can also be used in landscape restoration for listing and recovery of threatened ecological communities, identification and recovery of habitat for threatened species and endangered populations, and modelling the distribution of biological assets. In combination with other mapped landscape variables, they can be used to predict the pre-1750 distribution of biological entities. The NSW VCA plant community types are embedded within NSW State environmental regulatory systems, providing a platform for assessment in planning

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and regulatory frameworks under a range of State legislation. Similar frameworks also exist in other parts of Australia (e.g. Parkes *et al*. 2003, DERM 2011).

The central-southern NSW study area includes parts of the NSW South Western Slopes (SWS), Central West Slopes (CWS) and South Western Plains (SWP) botanical subdivisions (Anderson 1961) and parts of the South Western Slopes, Riverina and Cobar Peneplain bioregions (Thackway & Cresswell 1995). It is a very fragmented natural landscape. About 92.5% (2.4 million hectares) of the study area is managed as freehold agricultural land with an additional 4.6% (121,000 hectares) managed as Crown (primarily grazing) leasehold. Only 1.1% (28,500 hectares) is managed in formal conservation reserves, with 1.2% (31,540 hectares) in state forest, and 0.6% (16,626 hectares) in travelling stock reserves.

The region is characterised by broad areas of lowland ecosystems containing remnants of threatened plant communities, and the high proportion of agricultural land has led to habitat loss resulting from clearing and vegetation structural decline (DEH 2000). As such, it is a highly important region in which to develop information for prioritisation and targeting of investment for environmental restoration programs. Before the mapping presented here, the study area lacked fine thematic level (congruent with classification Level D in Sivertsen 2009) vegetation map data except for a few conservation reserves and one local government area.

Jurisdictional vegetation classifications have been mapped in other States including Victoria (Victorian DNR 2002, DSE 2011) and Queensland (Sattler & Williams 1999, Queensland Herbarium 2003, DERM 2011). Elsewhere, vegetation maps have aligned types with jurisdictional vegetation classifications including the mapping of Voygeours National Park in Minnesota in the United States (Faber-Langendoen *et al*. 2007), which related mapped units to the pre-existing United States National Vegetation Classification (Grossman *et al.* 1998, Jennings *et al.* 2006). Recent mapping in inland NSW with aligned mapped units to the NSW VCA plant communities include NGH Environmental (2008) mapping north of Broken Hill; Porteners (2011) map of Cobbora State Conservation Area near Dubbo; Westbrooke *et al.* (2011) map of part of Paroo-Darling National Park in far western NSW; Roff *et al.* (2010) SPOT5 imagery map of the Murray CMA area; and Bowen & Simpson (2009) sequential maps of the plant communities in the Gwydir wetlands near Moree.

For the fragmented landscapes in central-southern NSW, this study aimed to produce a highly accurate regional vegetation map expressing a fine thematic classification of plant community types and vegetation conditions using high resolution ADS40 digital imagery. In doing so, the study developed and refined a methodology utilising technological advances in digital airborne imagery and on-screen 3-D interpretation methods for mapping defined vegetation types.

### *Study Area*

The central-southern NSW study area covers an area of 2.6 million hectares encompassing the Coolamon, Cootamundra, Junee, Lockhart, Narrandera, Tarcutta, Urana, Wagga Wagga and Yanco 1:100,000 mapsheets and Ariah Park, Wallaroobie Range and Yoogali 1:50,000 mapsheets (Figure 1). It includes the Coolamon, Junee and Leeton local government areas in their entirety, as well as large portions of the Cootamundra, Griffith, Gundagai, Harden, Lockhart, Murrumbidgee, Narrandera, Temora, Urana and Wagga Wagga local government areas. Small parts of the Bland, Carathool,

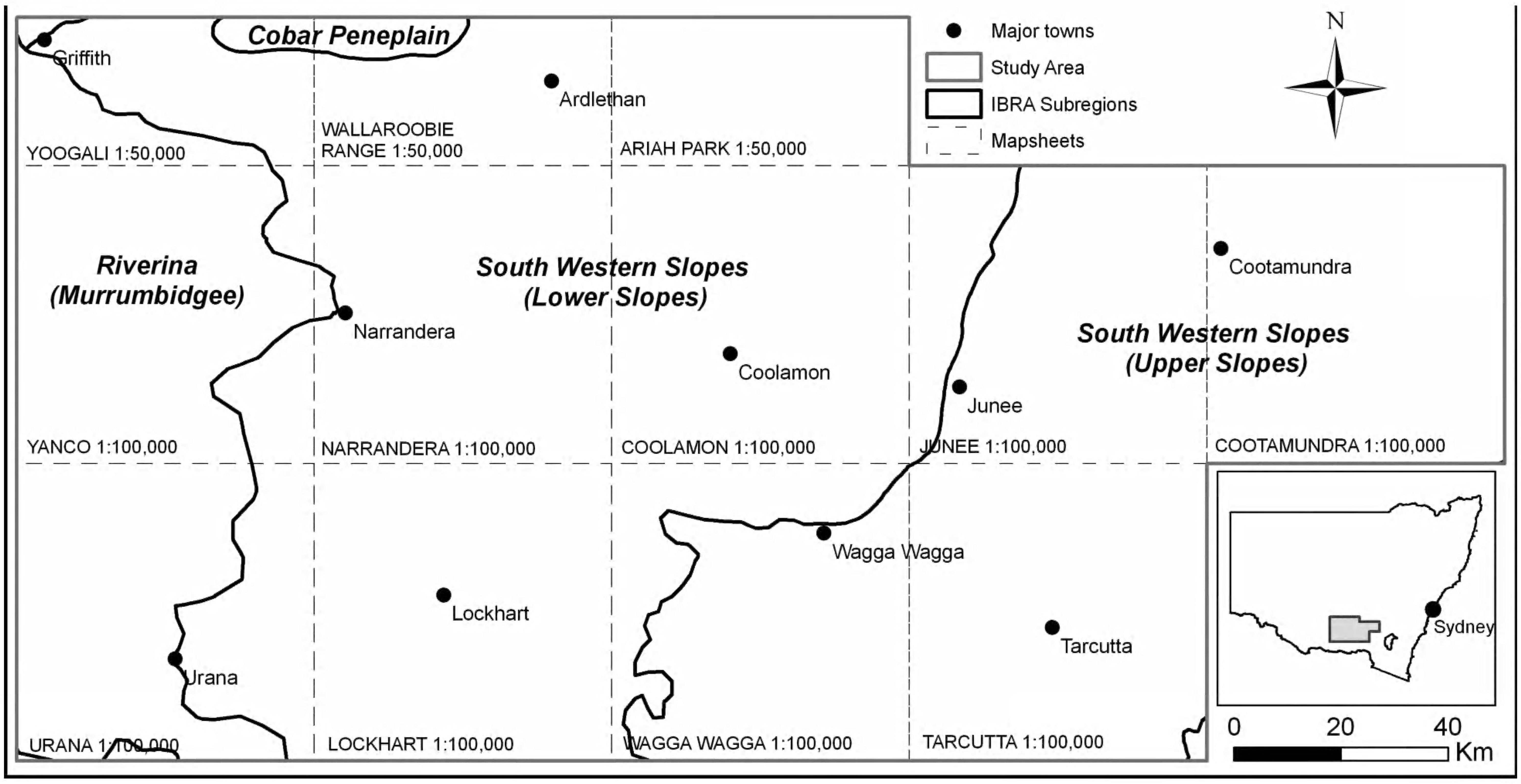

**Fig. 1.** The study area showing bioregions, subregions, topographic mapsheets and major towns.

Greater Hume, Jerilderie and Tumut local government areas are also mapped. The study area extends across portions of three NSW Catchment Management Authority (CMA) areas, including central parts of the Murrumbidgee CMA, the Urana – Lockhart part of the Murray CMA, and small areas along the southern boundary of the Lachlan CMA.

### *Climate*

The climate is temperate, characterised by hot dry summers and cool winters. Precipitation increases in areas of greater topographic relief in the east and is relatively even across seasons, with slightly less occurring in hotter months when evaporation rates are higher. Mean daily maximum and minimum temperatures are slightly higher in western parts of the study area, however temperature variance is relatively consistent. Climatic data for key weather stations within the study area is presented in Table 1 (BoM 2011).

### *Physiography*

The study area contains a variety of landforms and soils reflecting the broad variation between the NSW South Western Slopes, Riverina and Cobar Peneplain bioregions (Figure 1). The Riverina bioregion, in the west of the study area, includes most of the Urana and Yanco 1:100,000 mapsheets. It is characterised by broad alluvial floodplains and alluvial plain landform patterns composed of black to red clay and silt soils deposited by repeated flooding of the Murrumbidgee, Murray and Lachlan river systems (NPWS 2003, Tuckwell 1976, Wynn 1977). Landform elements include river channels, backplains, swamps, lakes and restricted areas of sandy lunettes formed in the Quaternary period.

The Cobar Peneplain occupies a small area in the north-west of the study area and includes northern sections of the Yoogali and Walleroobie Range 1:50,000 mapsheets. This area is characterised by low hills, plains and stony ranges formed on the northwesterly extension of the Lachlan Fold Belt (NPWS 2003) primarily composed of Barrat Conglomerates of the Cocopara Group of the Devonian period (Wynn 1977).

The NSW South Western Slopes bioregion comprises the majority of the study area, encompassing most of the land east of Narrandera and Urana and extending west towards Griffith on the Yoogali 1:50,000 mapsheet. It contains two sub-bioregions: the Lower Slopes in the west and the Upper Slopes in the east. Features of these subregions are described in NPWS (2003) and Benson (2008). The Lower Slopes subregion is characterised by alluvial valleys with undulating and hilly ranges and isolated peaks. The Upper Slopes subregion, which occurs east of Junee and Wagga Wagga, receives greater precipitation and contains greater topographic relief. It is characterised by Ordovician to Devonian folded and faulted sedimentary substrates and areas of intrusive granites and metasediments (Adamson & Loudon 1966, NPWS 2003, Tuckwell 1976, Warren *et al*. 1996, Wynn 1977).

### *Previous botanical studies*

Previous vegetation mapping and surveys for south western NSW are outlined in Benson (2008) for the NSW South Western Slopes bioregion and in Benson *et al*. (2006) for the Riverina and Cobar Peneplain bioregions. However, only a few of these previous studies were in the study area and most were botanical surveys rather than vegetation mapping. Moore (1953) described “plant associations” for most of the study area and produced a coarse scale, broad thematic level vegetation map. Brickhill (1985) assessed the conservation status of plant communities in the southern Riverina. Bos & Lockwood (1996) plot sampled some of the state forests in the study area and Benson *et al*. (1997) sampled and classified the native grasslands of the Riverina bioregion, including around Urana and Narrandera. Priday & Mulvaney (2005) sampled and described the vegetation of the Wagga Wagga Shire and Priday (2006) plot sampled the southern part of the NSW South Western Slopes bioregion. EcoGIS (2004) sampled and mapped a number of conservation reserves at fine scales from the southern tablelands to the Upper South Western Slopes and Gellie (2005) provided an initial overall classification of the vegetation for the southern part of the Upper Slopes subregion. Other conservation reserve mapping includes Porteners (2001, 2007) and Whiting (2006).

**Table 1. Climate data for key weather stations within the study area (BoM 2011).**

| **Location** | **Mapsheet** | **Altitude (m)** | **Mean daily max temp (°C) (Jan)** | **Mean daily min temp (°C) (Jul)** | **Lowest mean monthly rainfall (mm)** | **Highest mean monthly rainfall (mm)** | **Mean annual rainfall (mm)** |
|---|---|---|---|---|---|---|---|
| Cootamundra Airport | Cootamundra | 335 | 31.9 | 1.2 | 31.6 (May) | 59.6 (Jul) | 589.6 |
| Griffith Airport | Yoogali | 134 | 32.8 | 3.5 | 27.7 (Apr) | 48.5 (Oct) | 402.5 |
| Junee Treatment Works | Junee | 280 | 32.4 | 2.3 | 37.8 (Feb) | 51.3 (Oct) | 523.0 |
| Murrumburrah Old PO | Cootamundra | 370 | 32.1 | 0.8 | 42.9 (Feb) | 56.2 (Jun) | 606.4 |
| Narrandera Airport | Narrandera | 145 | 33.0 | 3.0 | 31.8 (Mar) | 43.8 (Oct) | 441.3 |
| Urana PO | Urana | 125 | 32.9 | 3.2 | 32.0 (Jan) | 45.0 (Jun) | 442.5 |
| Wagga Wagga Agricultural Institute | Wagga Wagga | 219 | 31.5 | 3.0 | 36.4 (Mar) | 52.7 (Oct) | 523.6 |
| Yanco Agricultural Institute | Yanco | 164 | 34.0 | 4.9 | 28.9 (Jan, Nov) | 39.6 (Oct) | 391.5 |

### *The NSW Vegetation Classification and Assessment database*

A comprehensive review and assessment of NSW vegetation datasets including plot analyses and map unit descriptions coupled with extensive field traverses and rapid sampling forms the basis of the NSW Vegetation Classification and Assessment database (Benson 2006). The NSW VCA aims to provide a consistent plant community classification across NSW and full distributional perspectives on extent, threats and protected area status for each classified plant community. As of 2011, the NSW VCA covered approximately 78% of NSW across 11½ bioregions west of the Great Dividing Range (Benson *et al.* 2010). The NSW VCA database also contains a range of protected area and threat assessments useful for conservation assessment and planning purposes. These include a set of threat criteria for grading each plant community into a threat code (Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern) and an audit of plant communities in all protected areas (public conservation reserves and secure property agreements) providing an assessment of the protected area status of each plant community (see descriptions of all NSW VCA fields in Benson 2006). For NSW VCA classification of plant communities in the NSW Western Plains, including the Riverina bioregion, see Benson *et al.* (2006), and South Western Slopes bioregion, see Benson (2008).

As the NSW VCA progresses, it is being submitted for incorporation into the NSW Government Vegetation Information System (VIS) vegetation classification (OEH unpub.a) database that links to the *BioMetric* plant community type dataset (OEH unpub.b) for use in natural resource management regulatory tools such as the Property Vegetation Plan Developer (Gibbons *et al.* 2005). These tools are used to assess land use change applications, incentive payments and development offset proposals under the *Native Vegetation Act 2003* and the Biobanking Assessment Methodology (DECC 2008). The NSW VCA informs listings and descriptions of threatened ecological communities under the NSW *Threatened Species Conservation Act 1995* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.* A consistent plant community type classification provides a common reference for Commonwealth, State and regional bodies to undertake strategic conservation planning. An expert Change Panel has been established within the NSW Government to update plant communities listed in the VIS vegetation classification (OEH unpub. a) and the regulatory *BioMetric* Tool (Gibbons *et al*. 2005). Procedures are in place for the Change Panel to deliberate on proposed additions, deletions, splits and descriptive changes to plant communities listed in these databases.

## Background

The study focussed on mapping NSW VCA plant communities that occur in the study area using high resolution ADS40 digital imagery. Cultural plantings including exotic pine plantations (mainly *Pinus radiata*) and native species re-vegetation plantings were also mapped.

### *ADS40 Imagery*

While the study applied many of the principles of traditional Aerial Photograph Interpretation (API), it harnessed high resolution airborne digital imagery known as ADS40 (Airborne Digital Sensor) being flown by the NSW Department of Land and Property Information. Since 2007 this imagery has been replacing existing wet-film aerial photography through digital image capture by a Leica ADS40 camera (Leica Geosystems 2004, Black & Peasley 2008), and is now available for most of the eastern half of NSW. The NSW Government's ADS40 imagery is captured at 50cm resolution (standard) with six transparent layers including 16-bit Red Green Blue (RGB) values, Near Infra Red (NIR) and two panchromatic bands, and may be captured at other scales by request. Even when utilising only RGB bands of the imagery, as in this study, such image detail allows for far greater depth of information than traditional wet film aerial photography. Important for vegetation mapping purposes, the high resolution level and increased sharpness of the imagery when viewed in 3-D increases the ability of Digital Aerial Photograph Interpretation (DAPI) operators to identify individual species signatures, phytogeography and ecotone boundaries between plant community types. Table 2 outlines the specifications of the ADS40 imagery in comparison with other imagery regularly used in making vegetation maps in Australia. Figure 2 contains a visual representation of the differences between imagery in a 2-D environment.

Twelve 1:100,000 mapsheet blocks of ADS40 images each comprising 11 to 12 north-south running strips of approximately 55 x 5km were used in the mapping process, with their lineage (Table 3) indicating the currency of the vegetation map product for each mapsheet.

### *Stereo Analyst and 3-D Planar technology*

Vegetation polygon attributes were interpreted and recorded through the use of the Stereo Analyst for ArcGIS (SAFA) extension (ERDAS 2010) within ArcGIS (ESRI 2011). DAPI was undertaken in a 3-D environment using methods similar to traditional API (DUAP 2000). The 3-D stereo environment was created by SAFA and viewed with 20 inch 3-D Planar screen technology (Planar 2011), allowing linework to be digitised directly onto the screen and attributed by the DAPI operator, thus enabling the data capture process to be commenced and completed entirely within the 3-D digital environment (Figure 3). This eliminates the traditional API process of scanning acetate overlays containing stereoscope interpreted linework traced over aerial photographs followed by manual data entry for attribution by non-API personnel, a process which was subject to errors for a number of reasons.

## The vegetation map

### *Existing vegetation information*

Pre-existing vegetation mapping products across portions of the study area (e.g. DEC 2006, DEC 2007, EcoGIS

**Table 2. ADS40 imagery specifications and comparisons with other imagery.**

| | **ADS40** | **Wet-film Aerial Photography** | **SPOT5** |
|---|---|---|---|
| **Coverage** | Most of the central and coastal divisions, all areas except western division to be flown by Spring 2012. Portions of the Western Division may be flown upon request. | State | State |
| **Resolution (GSD – ground sampling distance)** | 50 GSD (50 x 50cm pixel standard); range 10 GSD to 80 GSD | N/A. Scale variable, generally 1:50,000 or 1:25,000 | 500 GSD (5 x 5m pixel) to 1000 GSD (10 x 10m pixel). Can pan-sharpen to 250 GSD |
| **RGB** | 16-bit | 8-bit | 16-bit |
| **NIR** | Yes (2nd generation) | No | Yes |
| **Panchromatic bands** | Two | Nil | One (500 GSD); Nil (1000 GSD) |

2004, Gellie 2005, Maguire *et al*. 2000, Priday & Mulvaney 2005, Roberts & Roberts 2001, White *et al*. 2002) were not considered useful for guiding the capture and attribution of new vegetation polygon linework because they were:

- Captured at a coarser scale as they were developed through interpretation of relatively small scale wet-film photography;
- Subject to loss of spatial accuracy through the transfer of linework into the digital environment from acetate overlays used as part of traditional API processes; and
- Mapped to different (generally broader) plant community classifications, reducing the relevance of polygon delineation.

724 existing floristic plots across 19 previous flora surveys (Bedward *et al.* 2011) were reviewed, with suitable plot data providing useful checks to identify the vegetation type on the ground. Providing that plot data had been accurately georeferenced, DAPI operators used this information along with their own reconnaissance data when attributing vegetation polygons.

*Field reconnaissance and checking*

Before DAPI commenced, DAPI operators and botanists undertook reconnaissance of the study area to gain familiarity with the NSW VCA plant communities, their constituent plant species and relationship to landform position and soil type. Importantly, field checking provided an opportunity to correlate visual signatures on ADS40 imagery for each plant species and community. The majority of field observations were recorded by inspecting land in public tenure (national parks, state forests, roadside reserves, travelling stock reserves and council reserves), although some private tenure land was also checked. Where access to private land was not feasible, observations of dominant tree species and relationships with abiotic features were recorded using binoculars. The reconnassiance and checking process was repeated throughout the mapping study whereby DAPI operators and at times, botanists, field-checked vegetated landscapes to maximise correlations between field observations and signatures on the ADS40 imagery. All information was recorded directly in the field onto printed ADS40 imagery, or through georeferenced data capture.

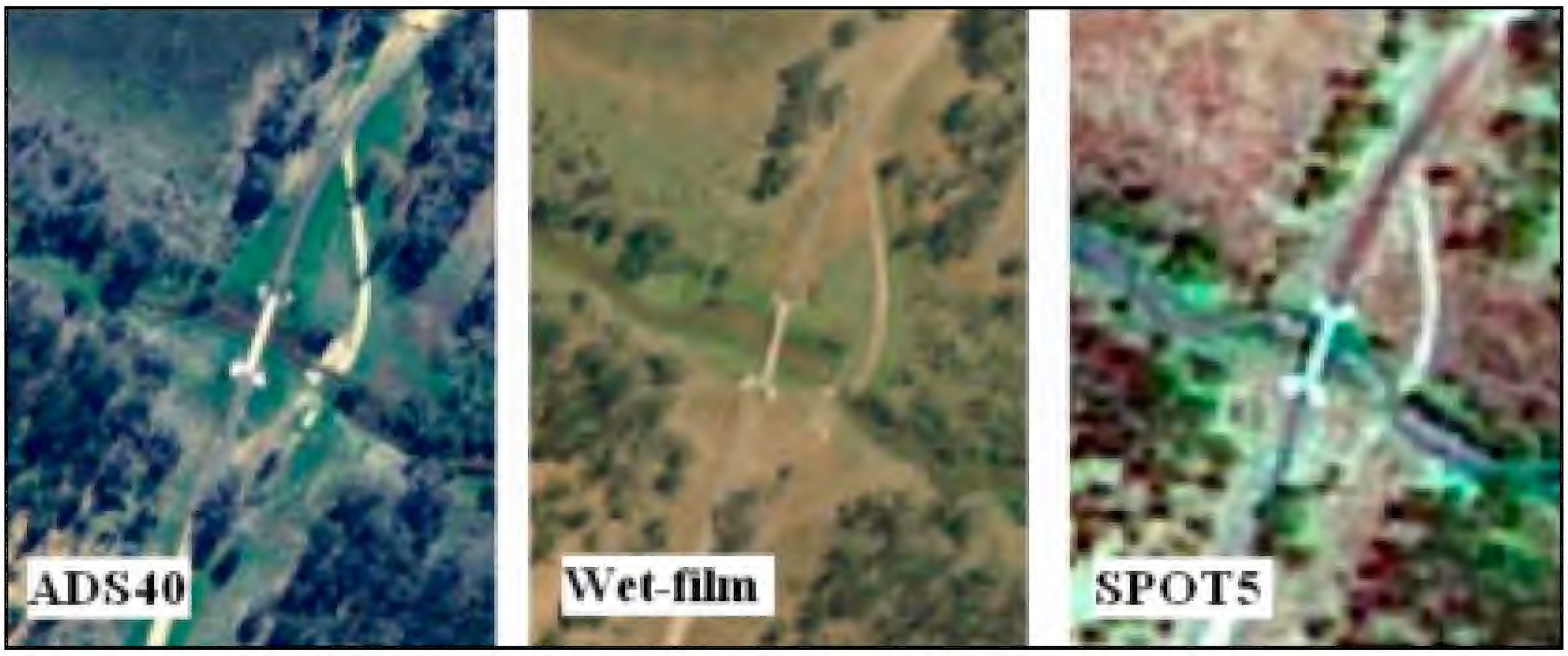

**Fig. 2.** Visual differences between ADS40, wet-film aerial photography and SPOT5 imagery (Black & Peasley 2008).

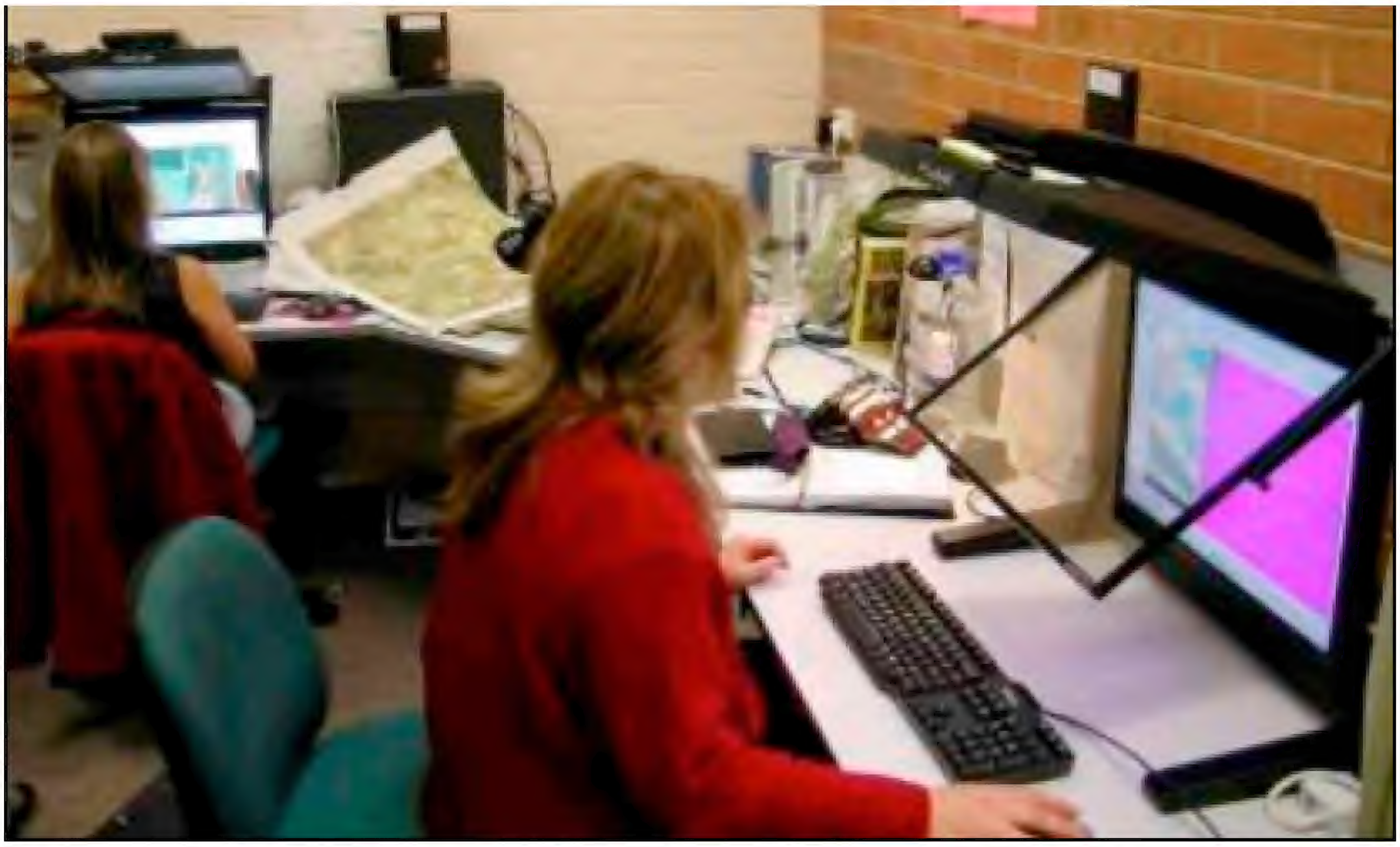

**Fig. 3**. DAPI operators at 3-D Planar workstations using Stereo Analyst for ArcGIS map software.

### *Digital Aerial Photograph Interpretation*

The methods and principles of traditional API are well documented (e.g. DUAP 2000) and this method has been used for most vegetation mapping programs throughout the world, including in NSW. This study varied from the usual methods of API by using high resolution ADS40 imagery with image interpretation occurring directly on-screen in a 3-D GIS environment. The image interpretation used a 3-D SAFA platform (ERDAS 2010) to capture information into a 3-D polygon shapefile. The differences between traditional API and DAPI are listed in Table 4.

Interpretation of NSW VCA plant community types using ADS40 imagery was based on the identification of the ADS40 photo signatures of plant canopy species, and at times understorey structure, present in an area. Once this mix of species was determined through DAPI, the interpreter assigned the most appropriate VCA type in conjunction with factors such as landscape position and geographic distribution. Correlating field observations with various vegetation signatures observed on 3-D ADS40 imagery was critical to the mapping exercise. Differences in interpretation of signatures between DAPI operators were minimised by cross checking and undertaking joint field inspections. Use of botanically astute DAPI operators in conjunction with field observation was particularly important in mapping mixed eucalypt forests and woodlands, where even with high

**Table 3. Lineage of ADS40 image sets used in this study.**

| Image | Lineage |
|---|---|
| Ardlethan (Wallaroobie Range 1:50,000) | 12/2007 |
| Barmedman (Ariah Park 1:50,000) | 10/2007 |
| Coolamon | 9/2007 |
| Cootamundra | 1/2008 |
| Griffith (Yoogali 1:50,000) | 2/2008 |
| Junee | 9/2007 |
| Lockhart | 9/2008 |
| Narrandera | 10/2007 |
| Tarcutta | 3/2010 |
| Urana | 4/2008 |
| Wagga Wagga | 4/2008 |
| Yanco | 2/2008 |

**Table 4. Differences between traditional API and DAPI.**

| | Traditional API | DAPI with ADS40 imagery |
|---|---|---|
| Data Capture | On acetates draped over Aerial Photographs, with a secondary process to scan linework and enter attribution data | Directly on screen in a 3-D shapefile |
| Scale | As per wet-film photography | Essentially ‘scale-less’, as the interpreter can use digital zoom functions. Image begins to lose quality at *circa* 1:1,000. |
| Viewing Platform | Stereoscope | 3-D Planar Screen (Figure 3) or other 3-D platform, allowing for multiple-viewers and increased ability to conference complex decisions. |
| Image quality [1] | Moderate | High |

[1] refer to Table 2 and Figure 2 for image comparison

resolution imagery one plant community type may exhibit several patterns in both natural and modified environments (e.g. different growth stages, densities and topographic situations). Further fieldwork was sometimes undertaken after intial DAPI to refine map polygon attributes and plant community boundaries.

As the information was captured directly into ArcGIS using the SAFA extension, DAPI operators were able to use the SAFA zoom functions, thus improving the scale of capture. DAPI operators also utilised the SAFA colour tuning functions to distinguish and more clearly separate differing species to greater degrees, including the various colour stretch modes in combination with degrees of brightness and contrast. As a guide, DAPI operators were encouraged to draw polygons at an optimal zoom scale of 1:4,000, however at times it was necessary to zoom in beyond this level to determine the suite of canopy species in complex areas. The operational environment of the Stereo Analyst for ArcGIS interface is shown in Figure 4.

All naturally vegetated areas of greater than one hectare were mapped including non-woody vegetation such as native grasslands and swamps. Some smaller areas were also mapped including linear remnants along roadsides with a width of two or more tree crowns. Single rows of trees were not mapped, but single rows on each side of a road or creek were mapped as one polygon with the road or creek included. Areas with greater than 5% crown cover were mapped as woody vegetation. In order to enhance the utility of the final vegetation map product beyond that of a standard plant community type map, a suite of additional attributes were collected for each polygon (Table 5). Polygons were driven by NSW VCA type, but split on dominant species, density class and/or crown condition. Thus, polygons of a single NSW VCA plant community type may contain several polygons split on these attribute variations. All other attributes within a polygon were only to provide additional information. Collecting additional attributes allows map users to develop multi-attribute models to answer a range of ecological questions beyond that of a standard vegetation map.

The attributes of NSW Vegetation Class, NSW Threatened Ecological Community, NSW VCA Threat Category, % Cleared, % Remaining, Over 70% Cleared and Source % Cleared Estimate were added to the shapefile post-DAPI data capture. Consistency of attribution was achieved between DAPI operators through regular cross-checks among themselves and botanists. Decision rules were developed for determining the differences between similar NSW VCA plant community types.

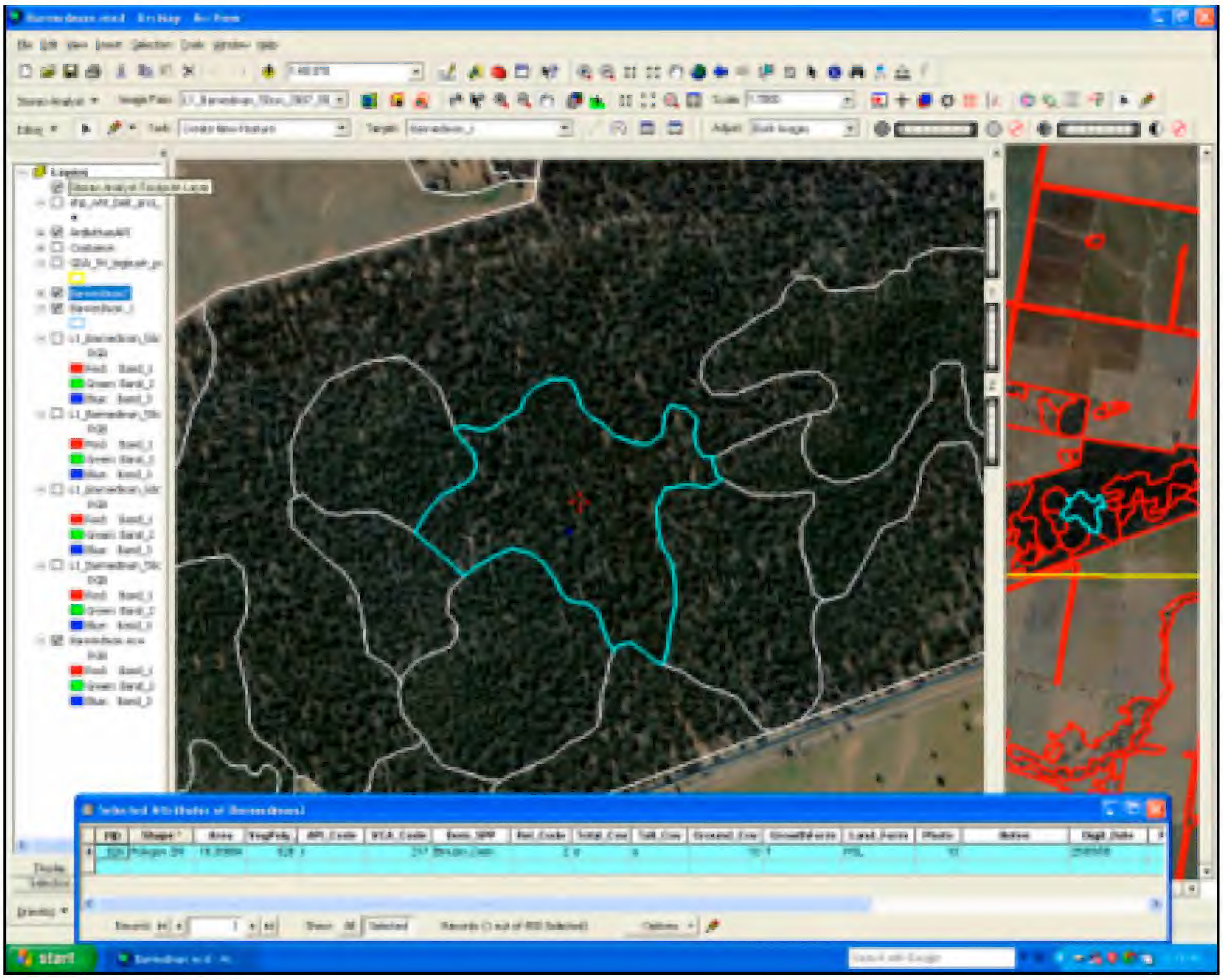

**Fig. 4**. Stereo Analyst – ArcGIS screen interface. Stereo window (at centre) and ArcMap window (right). The same polygon is selected in each window and its record in the attribute table.

**Table 5. Polygon attributes captured as part of the study.**

| | |
|---|---|
| **Land Cover** | Agricultural Land; Agricultural Land 20–50% rock; Bare earth; Natural wetlands; Non-woody native vegetation with previous cultivation pattern observed on imagery < 20% rock; Non-woody native vegetation with previous cultivation pattern observed on imagery 20–50% rock; Woody native vegetation with previous cultivation pattern observed on imagery; Non-woody native vegetation without previous cultivation pattern observed on imagery; Non-woody native vegetation without previous cultivation pattern observed on imagery <20% rock; Non-woody native vegetation without previous cultivation pattern observed on imagery 20–50% rock; Non-woody native vegetation without previous cultivation pattern observed on imagery 50–70% rock; Non-woody native vegetation without previous cultivation pattern observed on imagery > 70% rock; Non-natural; Not identified; Open water; Woody vegetation; Woody vegetation 20–50% rock; Woody vegetation 50–70% rock; Woody vegetation > 70% rock; Woody native vegetation with previous cultivation pattern observed on imagery; Woody native vegetation with previous cultivation pattern observed on imagery < 20% rock; Woody native vegetation with previous cultivation pattern observed on imagery 20–50% rock |
| **Aggregate** | Aggregate code for vegetation within the polygon: Acacias; Casuarinas; Commercial plantations; Cypress pine; Environmental plantations; Eucalypts; Native/derived grassland; Shrub mosaic; Swamp mosaic; Excluded (not native vegetation) |
| **NSW VCA ID** | Identification code for NSW VCA type: e.g. ID186 |
| **NSW VCA Plant Community Type Name** | Plant community type name for NSW VCA type: e.g. Dwyers Red Gum - Black Cypress Pine - Currawang shrubby low woodland on rocky hills mainly in the NSW South-western Slopes bioregion |
| **Hectares** | Hectare area within the polygon |
| **Dominant Species 1** | Dominant species in polygon (generally tallest stratum): e.g *Eucalyptus dwyeri* |
| **Dominant Species 2** | 2nd dominant species in polygon (generally tallest stratum): e.g. *Callitris endlicheri* |
| **Dominant Species 3** | 3rd dominant species in polygon (generally tallest stratum): e.g. *Allocasuarina verticillata* |
| **Reliability** | For NSW VCA plant community type and dominant species: Verified (polygon verified on ground, or strong obvious features); High Confidence (high certainty of features /species interpretation, confident extrapolation from localised sampling); Moderate Confidence (moderate certainty of features, some similarity with features sampled elsewhere, some uncertainty in species interpretation ); Educated Guess ( low certainty of features, remote area, inconsistent with features sampled elsewhere, low confidence in species interpretation ) |
| **Total Woody Cover** | Density of all native woody vegetation (woody groundcover excepted): None; 0-1%; 1-5%; 5-10%; 10-20%; 50-80%; >80%; <1% in clumps; 1-5% in clumps; 5-10% in clumps; 10-20% in clumps; Not relevant |
| **Tall Cover** | Density of native woody vegetation in tallest stratum: None; 0-1%; 1-5%; 5-10%; 10-20%; 50-80%; >80%; <1% in clumps; 1-5% in clumps; 5-10% in clumps; 10-20% in clumps; Not relevant |
| **Regrowth** | Density of woody regrowth (as a % of Tall Cover): None; 0-1%; 1-5%; 5-10%; 10-20%; 50-80%; >80%; <1% in clumps; 1-5% in clumps; 5-10% in clumps; 10-20% in clumps; Not relevant |
| **Crown Condition** | Condition rating for canopy species: Good health (healthy crowns); Moderate Health (some crown dieback at limb extremities); Poor health (advanced crown dieback, pronounced bayonets); Dead/poor health (near dead, or dead stags). |
| **Ground Cover** | Descriptor code for groundcover within the polygon: Barren; Chenopods with native grasses; Cropping/improved pastures; Heath; Native grasses; Native/naturalised grasses; Naturalised grasses; Rock (>70%); Sand ridge; Sedge/rush/fern/wet species; Shrub mosaic; Not identifiable; Not assessed; Not present |
| **Growth Form** | Chenopod shrub; Fern; Forb; Heath shrub; Hummock grass; Mallee; Mallee shrub; Moss; Rush; Sedge; Shrub; Sod grass; Tree; Tussock grass; Vine; Not relevant |
| **Landform** | Dominant landform within the polygon. Refer to Walker & Hopkins (1990) |
| **Notes** | Additional information recorded by DAPI operator |
| **Map Sheet** | 1:100,000 mapsheet name |
| **Photo** | Number of ADS40 photo strip |
| **Photo Date** | Date of capture of ADS40 image |
| **Digitiser** | Name of Remote Image Interpreter |
| **Digitising Date** | Date of digitising of polygon |
| **NSW Vegetation Class** | NSW Vegetation Class as per Keith (2004) |
| **Threatened Ecological Community** | Name and Status of Threatened Ecological Community under the NSW *Threatened Species Conservation Act 1995* or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* |
| **NSW VCA Threat Category** | Threat category as per Benson (2006): Critically endangered; Endangered; Vulnerable; Near Threatened; Least Concern |
| **% Cleared** | Percent of NSW VCA plant community type cleared |
| **% Remaining** | Percent of NSW VCA plant community type remaining |
| **Over 70% Cleared** | NSW VCA plant community types with greater than 70% cleared (less than 30% remaining) |
| **Source % Cleared Estimate** | Source of clearing estimate data (OEH unpub. b; Benson *et al.* 2010) |

### *Geographic Information System (GIS) post-processing*

Post-mapping GIS editing and processing was undertaken using ArcGIS. All 3-D shapefiles were first converted to 2-D and edgematchings were completed using a 2-D orthophoto as a base to ensure a seamless multi-attribute product across mapsheet boundaries and enable the various shapefiles to be merged into one. Topology errors resulting from the 3-D to 2-D conversion were corrected and any coding errors investigated and amended.

### *Feedback to the NSW VCA*

Where polygons could not be clearly attributed to a particular NSW VCA plant community type, DAPI operators and botanists liaised directly with the NSW VCA administrator to determine whether a NSW VCA plant community type could accommodate slight variation or whether a potential new plant community type had been identified. For potential new plant communities, field information was gathered and compared with compositionally similar existing NSW VCA plant communities. The mapping process also provided feedback to the NSW VCA administrator on changes in the geographic extent of NSW VCA plant communities such as amending occurrences in Local Government Areas or sub-bioregions. On occasion, the NSW VCA administrator undertook field survey with DAPI operators to provide perspective on how particular areas may fit into the NSW VCA plant commuity type classification.

### *Independent Accuracy Assessment*

Independent third-party accuracy assessment of completed mapsheets was incorporated. Independent botanists collected field data and undertook double-blind analysis of NSW VCA plant community type attribution (EcoLogical 2009, 2010, 2011a, 2011b, GHD unpub., SKM 2009).

The native vegetation footprint of the mapsheets was provided to independent assessors, and stratified using Mitchell landscapes (Mitchell 2003), an abiotic landscape classification considered appropriate as a surrogate for differences in vegetation without making specific inference to NSW VCA plant community types. Within stratified areas, random field validation points were allocated and restricted to within 100 m of all public tenure and selected private tenured parcels. Decision rules were developed to randomly allocate field validation plots within stratified units across the mapsheets. Plot (50 x 50 m) information collected at georeferenced field validation points comprised the three dominant plant species in each stratum, landform element (Walker & Hopkins 1990), NSW VCA plant community type (and if applicable 2nd and 3rd options where field decisions were not clear), and additional notes including canopy species within the same apparent plant community type within the direct viewshed from the validation point. While validation was undertaken after the final mapping product was completed, NSW VCA plant community types are robustly defined to ensure that seasonality is a negligible issue in sampling and determining plant community types.

Independent third-party botanists were not provided with the final NSW VCA plant community type map product until all field validation point data had been gathered in order to remove any potential bias in field observations. Accuracy assessment was then undertaken through GIS by intersecting the final NSW VCA plant community type map product with the georeferenced field data to determine ‘degrees of correctness’ as per Table 6 (modified from Gopal & Woodcock 1994) in accordance with the NSW Interim Vegetation Type Mapping Standard (Sivertsen 2009).

## Results

### *Mapped Plant Community Types*

A total of 100 NSW VCA plant community types were mapped across the study area (listed in Table 7 with an example of the mapping in Figure 5). A total of 546,151 hectares of native vegetation (20.5% of the study area) was mapped, with 13.5% (358,594 hectares) comprising treed woody vegetation types, 4,336 hectares of shrubland (including chenopod shrublands and ‘Shrub Mosaic), 5,343 hectares of native/derived grassland types and 663 hectares of wetland types. A further 177,215 hectares of non-woody native vegetation were mapped into broader mosaics of communities without specific NSW VCA plant community type attribution. This included 148,130 hectares of ‘Native Grassland Mosaic’ with 3,260 hectares containing an observed cultivation pattern, and 29,085 hectares of ‘Swamp Mosaic’. A total of 31,511 hectares (8.8% of extant native woody vegetation) persists as paddock remnant vegetation with a cropped or exotic understorey.

The mapping process identified one new community (NSW VCA 426) defined with agreement, checking and sampling by the NSW VCA administrator. Dominant species attribution of each polygon should assist updating of plant community type attribution for relevant polygons over time if there are revisions of the NSW VCA plant communities, although the latter would be mainly driven by full floristic plot analyses and expert review.

Native grassland, swamp and shrub mosaics were mapped where a number of NSW VCA plant community types occurred at a finer scale than DAPI operators were able to delineate within project timelines. In these instances, mapping of woody vegetation was prioritised. There were also some instances where spatial distributions of these NSW VCA plant community types were below the minimum polygon size, were ephemeral in nature or could only be distinguished with detailed site-based field survey in the absence of temporal synchronisation between ADS40 image capture and field survey. Native grassland mosaics were not differentiated into natural (non-woody in pre-European times) and derived grasslands (e.g. where trees have been removed since European settlement). However, it is considered that most of the grasslands of the eastern Riverina bioregion are primarily natural (McDougall 2008), whereas grasslands of the NSW South Western Slopes and Cobar Peneplain bioregions are

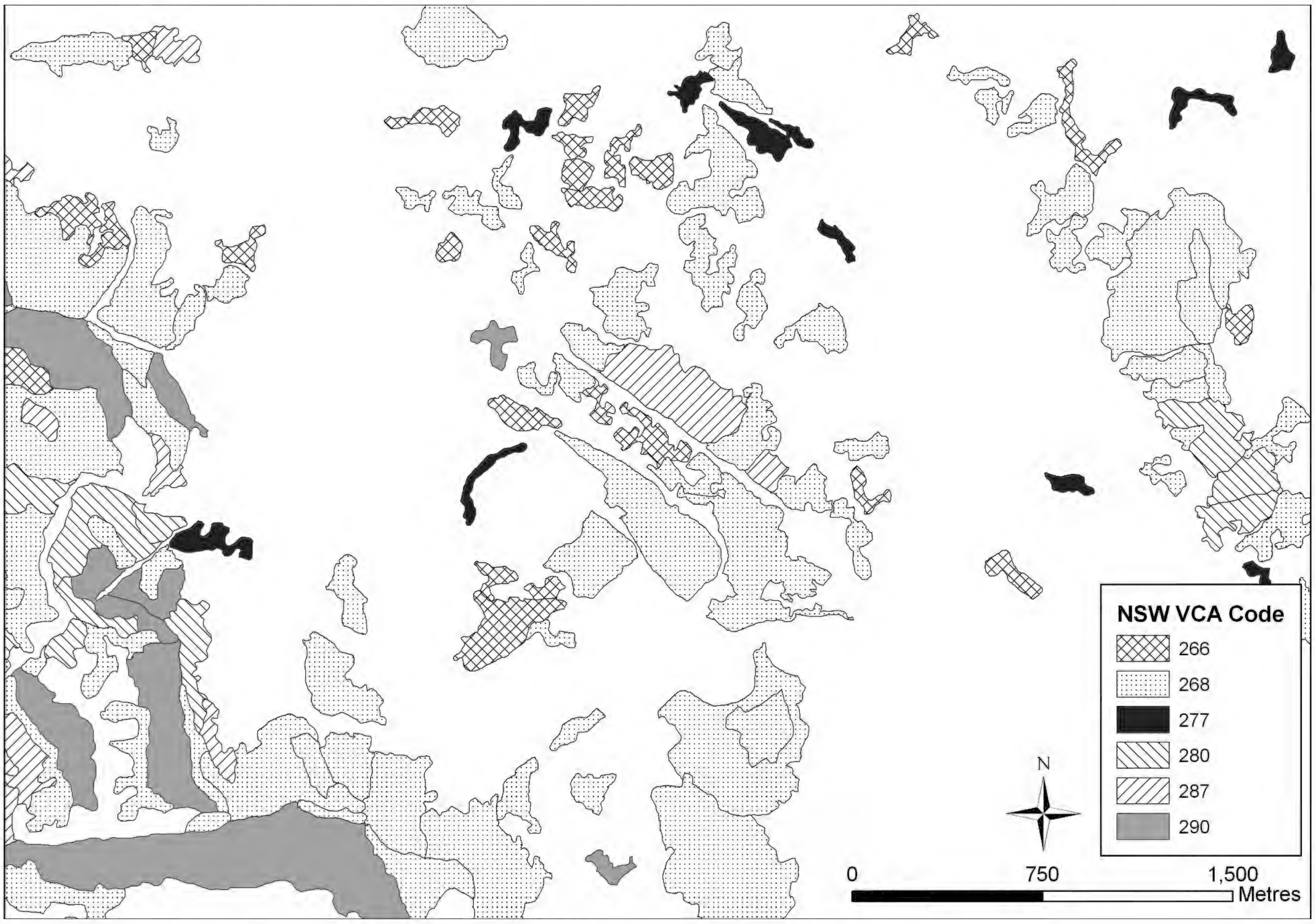

**Fig. 5.** Section of the Tarcutta 1:100,000 mapsheet showing the polygon detail able to be accurately mapped using ADS40 imagery. NOTE: Where polyon of the same NSW VCA type adjoin they are split on dominant speices mix, crown density or crown condition.

primarily derived from tree clearing. There may be small remnants of natural grassland in the lower slopes subregion of the NSW South Western Slopes bioregion.

The area of treed remnants with cropped ground cover (approximately 9% of the study area) along with a very large area of scattered paddock trees below 5% crown cover that are not mapped as native vegetation, supports the findings about remnant woody vegetation in Gibbons & Boak (2002) in their study of the nearby Holbrook region. Isolated trees are particularly common in the lowland plant communities within the Floodplain Transition Woodlands, Riverine Plain Woodlands and Western Slopes Grassy Woodlands NSW Vegetation Classes. Some of these plant communities are part of threatened ecological community listings under the NSW *Threatened Species Conservation Act 1995* and/or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.* Some NSW VCA plant community types were mapped over a small extent as they were either naturally restricted in distribution, highly cleared within the region or the study area represented the edge of their geographic distribution.

Planted woody vegetation (primarily commercial *Pinus radiata* plantations and small-scale shelterbelt plantings) represented 18,623 hectares of the study area.

Descriptions of the 100 NSW VCA plant communities mapped in this study are found in Appendix A with the twelve vegetation maps saved as PDF files in Appendix B. The original ArcGIS shapefile is available under licence by emailing data.broker@environment. nsw.gov.au or http:// mapdata.environment.nsw.gov.au/DDWA/.

### *Independent Accuracy Assessment*

A total of 1,041 blind field validation plots were collected and analysed across the study area (Figure 6), yielding an overall user accuracy of 87 %. Attribution accuracy for NSW VCA plant community types is presented in Table 8, with accuracy categorised by the broad NSW Vegetation Classes of Keith (2004). For woody vegetation types, the number of validation plot samples is relatively proportional to the extent of each NSW Vegetation Class across the study area, with a mean sampling intensity of one plot per 385 hectares. Due to access issues, vegetation types within non-woody NSW Vegetation Classes were validated at a lower intensity of one plot per 1,790 hectares. NSW VCA plant communities within five NSW Vegetation Classes (North-west Plain Shrublands – 184 ha; North-west Floodplain Woodlands – 154 ha; Semi-arid Sand Plain Woodlands – 89 ha; Southern Tableland Dry Sclerophyll Forests – 955 ha; and Southern Tableland Wet Sclerophyll Forests – 32 ha), were not sampled in the accuracy assessment process as they were of minimal extent in the study area.

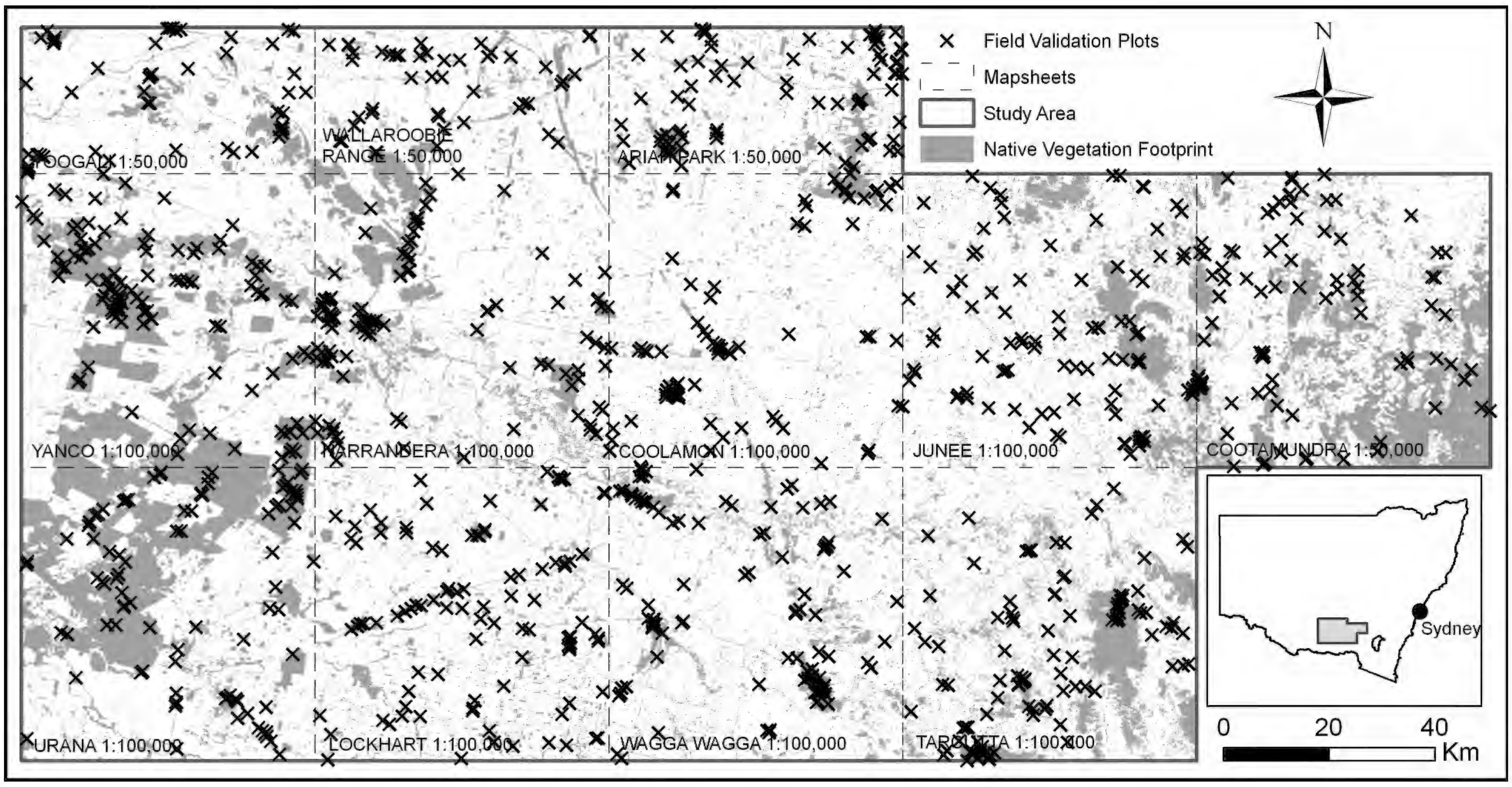

**Fig. 6**. Location of independent blind accuracy assessment plots.

## Discussion

### *Use of digital stereo imagery*

The mapping of 100 NSW VCA plant communties within the South Western Slopes and Riverina bioregions in central-southern NSW, one of the most highly fragmented landscapes in Australia, provides spatial data for environmental planning and assessment. The quality of the mapping is similar to fine thematic mapping of plant communities in parts of Europe and Great Britain (Bradtner *et al*. 2011). In Switzerland the Swiss Federal Institute of Forest, Snow and Landscapes has interpreted ADS40 imagery using Stereo Analyst for ArcGIS software and 3D Planar screen hardware to undertake forest inventory and other ecological assessments (Hastedt *et al.* 2009a & 2009b), while the National Inventory of Landscapes in Sweden (NILS) programs aerial photo interpretation approach (Allard *et al.* 2003) uses Planar screens with similar software (DAT/EM's Summit Evolution) for stereo observation and delineation, with ArcGIS used for polygon generation and registering interpreted data into their database (Heiskanen *et al.* 2008). This study in central-south NSW represents the first time the software has been used to develop a regional vegetation map in Australia. Stereo Analyst software had been used by Forests NSW for forest inventory assessments, however, this was undertaken using Cathode-Ray Tube (CRT) screens and flicker glasses to interpret scanned wet-film aerial photography contact prints in a digital 3-D environment (Webster 2008, Webster & Turner 2007).

High resolution ADS40 multi-spectral imagery produced maps with high pixel accuracy and greater image depth than traditional API mapping using wet-film aerial photography (DUAP 2000). The resolution of the ADS40 imagery, along with a systematic DAPI process including extensive field checking, is more likely to produce accurate mapping at the fine hierarchical level of a plant community ('plant association' in Beadle & Costin 1952, 'plant community' in Benson 2006, 'Classification Level D' in Sivertsen 2009), than interpretation of digital satellite imagery such as SPOT5 or LANDSAT TM, which is captured at a coarser scale and

**Table 6. Accuracy assessment degrees of correctness (Sivertsen 2009).**

| Accuracy Level | Degree of Correctness | Description |
|---|---|---|
| 1 | Absolutely Right | No doubt about the match. **Perfect** |
| 2 | Reasonable or Acceptable Answer | May not be the best possible but is acceptable; this does not pose a problem to the user if it is seen on the map. **Right** |
| 3 | Understandable but Wrong | Not good; there is something about the site that makes the answer understandable but there is clearly a better answer. This answer would pose a problem for users of the map. **Not Right** |
| 4 | Absolutely Wrong | Absolutely unacceptable. **Very wrong** |

**Table 7. NSW VCA plant communities mapped in the study area listed under NSW Vegetation Formations and Classes (Keith 2004).**

| ID | NSW VCA Plant Community Type | Hectares |
|---|---|---|
| **Wet Sclerophyll Forests** | | |
| **Southern Tableland Wet Sclerophyll Forests** | | |
| 295 | Robertson's Peppermint - Broad-leaved Peppermint - Norton's Box - stringybark shrub-fern open forest of the NSW South Western Slopes and South Eastern Highlands Bioregions | 13 |
| 300 | Ribbon Gum - Narrow-leaved (Robertson's) Peppermint montane fern - grass tall open forest on deep clay loam soils in the upper NSW South Western Slopes Bioregion and western Kosciuszko escarpment | 19 |
| **Grassy Woodlands** | | |
| **Southern Tableland Grassy Woodlands** | | |
| 283 | Apple Box - Blakely's Red Gum moist valley and footslopes grass-forb open forest of the NSW South Western Slopes Bioregion | 263 |
| 312 | Yellow Box grassy tall woodland on valley flats in the upper slopes of the South Western Slopes and South Eastern Highlands Bioregions | 2 |
| **Western Slopes Grassy Woodlands** | | |
| 266 | White Box grassy woodland in the upper slopes sub-region of the NSW South Western Slopes Bioregion | 26,437 |
| 267 | White Box - White Cypress Pine - Western Grey Box shrub/grass/forb woodland in the NSW South Western Slopes Bioregion | 4,893 |
| 268 | White Box - Blakely's Red Gum - Long-leaved Box - Norton's Box - Red Stringybark grass-shrub woodland on shallow soils on hills in the NSW South Western Slopes Bioregion | 10,863 |
| 276 | Yellow Box grassy tall woodland on alluvium or parna loams and clays on flats in NSW South Western Slopes Bioregion | 2,411 |
| 277 | Blakely's Red Gum - Yellow Box grassy tall woodland of the NSW South Western Slopes Bioregion | 24,946 |
| 278 | Riparian Blakely's Red Gum - box - shrub - sedge - grass tall open forest of the central NSW South Western Slopes Bioregion | 298 |
| 280 | Red Stringybark - Blakely's Red Gum -/+ Long-leaved Box shrub/grass hill woodland of the NSW South Western Slopes Bioregion | 9,949 |
| 282 | Blakely's Red Gum - White Box - Yellow Box - Black Cypress Pine box grass/shrub woodland on clay loam soils on undulating hills of central NSW South Western Slopes Bioregion | 4,969 |
| 284 | Red Stringybark - Blakely's Red Gum - tea tree herbaceous swampy valley open forest of the southern NSW South Western Slopes Bioregion | 10 |
| 301 | Drooping Sheoke - *Ricinocarpos bowmannii* - grasstree tall open shrubland of the Coolac - Tumut Serpentinite Belt | 143 |
| 316 | Norton's Box - Red Box - Red Stringybark -/+ Nodding Flax Lily forb-grass open forest mainly on the Tumut region | 32 |
| 347 | White Box - Blakely's Red Gum shrub/grass woodland on metamorphic hillslopes in the mid-southern part of the upper slopes sub-region of the NSW South Western Slopes Bioregion | 4,679 |
| 426 | Red Box - White Box +/- Red Stringybark hill woodland in the NSW South Western Slopes Bioregion | 178 |
| **Floodplain Transition Woodlands** | | |
| 56 | Poplar Box - Belah woodland on clay-loam soils on alluvial plains of north-central NSW | 19 |
| 70 | White Cypress Pine woodland on sandy loams in central NSW wheatbelt | 7,857 |
| 74 | Yellow Box - River Red Gum tall grassy riverine woodland of NSW South Western Slopes and Riverina Bioregions | 11,839 |
| 76 | Western Grey Box tall grassy woodland on alluvial loam and clay soils in the NSW South Western Slopes and Riverina Bioregions | 8,392 |
| 80 | Western Grey Box - White Cypress Pine tall woodland on loam soil on alluvial plains of NSW South Western Slopes and Riverina Bioregions | 44,991 |
| 82 | Western Grey Box - Poplar Box - White Cypress Pine tall woodland on red loams mainly of the eastern Cobar Peneplain Bioregion | 10,796 |
| 237 | Riverine Western Grey Box grassy woodland of the semi-arid (warm) climate zone | 1,410 |
| 248 | Mixed box eucalypt woodland on low sandy-loam rises on alluvial plains in central western NSW | 48 |
| **Grasslands** | | |
| **Riverine Plain Grasslands** | | |
| 44 | Forb-rich Speargrass - Windmill Grass - White Top grassland of the Riverina Bioregion | 1,941 |
| 45 | Plains Grass grassland on alluvial mainly clay soils in the Riverina and NSW South Western Slopes Bioregions | 2,224 |
| 46 | Curly Windmill Grass - speargrass - wallaby grass grassland on alluvial clay and loam on the Hay Plain, Riverina Bioregion | 169 |
| 165 | Derived corkscrew grass grassland/forbland on sandplains and plains in the semi-arid (warm) climate zone | 1,009 |
| n/a | Native grassland (can include mosaics of some or all of the above four NSW VCAs) | 148,130 |
| **Dry Sclerophyll Forests** | | |
| **Upper Riverina Dry Sclerophyll Forests** | | |
| 285 | Broad-leaved Sally grass - sedge woodland on valley flats and swamps in the NSW South Western Slopes and adjoining South Eastern Highlands Bioregions | 149 |
| 289 | Mugga Ironbark - Inland Scribbly Gum - Red Box shrub/grass open forest on hills in the upper slopes sub-region of the NSW South Western Slopes Bioregion | 3,562 |

| ID | NSW VCA Plant Community Type | Hectares |
|---|---|---|
| 290 | Red Stringybark - Red Box - Long-leaved Box - Inland Scribbly Gum tussock grass - shrub low open forest on hills in the southern part of the NSW South Western Slopes Bioregion | 12,486 |
| 294 | Norton's Box - Red Box - White Box tussock grass open forest of the southern section of the NSW South Western Slopes Bioregion | 5 |
| 297 | Broad-leaved Peppermint - Norton's Box - Red Stringybark tall open forest on red clay on hills in the southern part of the NSW South Western Slopes Bioregion | 2 |
| 298 | Apple Box - Norton's Box - Blakely's Red Gum valley flat moist grassy tall open forest in the southern NSW South Western Slopes and adjoining South East Highlands Bioregions | 282 |
| 306 | Red Box - Red Stringybark - Norton's Box hill heath shrub - tussock grass open forest of the Tumut region | 303 |
| 310 | Norton's Box - Red Stringybark grassy tall open forest on sheltered slopes in the Tumbarumba - Murray River region of the NSW South Western Slopes Bioregion | 453 |
| 342 | Mugga Ironbark - mixed box woodland on hills in the Cowra - Boorowa - Young region of the NSW South Western Slopes Bioregion | 2,855 |
| **Southern Tableland Dry Sclerophyll Forests** | | |
| 299 | Riparian Ribbon Gum - Robertsons Peppermint - Apple Box riverine very tall open forest of the NSW South Western Slopes and South East Highlands Bioregions | 630 |
| 352 | Red Stringybark - Blakely's Red Gum hillslope open forest on meta-sediments in the Yass - Boorowa - Crookwell region of the NSW South Western Slopes and South Eastern Highlands Bioregions | 325 |
| **Western Slopes Dry Sclerophyll Forests** | | |
| 54 | Buloke - White Cypress Pine woodland in the NSW South Western Slopes Bioregion | 11 |
| 110 | Western Grey Box - Cypress Pine shrubby woodland on stony footslopes in the NSW South Western Slopes and Riverina Bioregions | 1,908 |
| 217 | Mugga Ironbark - Western Grey Box - cypress pine tall woodland on footslopes of low hills in the NSW South Western Slopes Bioregion | 16,011 |
| 243 | Mugga Ironbark - White Cypress Pine woodland on low rises mainly in the Cobar Peneplain Bioregion | 10 |
| 287 | Long-leaved Box - Red Box - Red Stringybark mixed open forest on hills and hillslopes in the NSW South Western Slopes Bioregion | 4,175 |
| 291 | Inland Scribbly Gum - Black Cypress Pine - Mugga Ironbark - Daphne Heath low woodland of the Wagga Wagga region in the southern NSW South Western Slopes Bioregion | 2,015 |
| 309 | Black Cypress Pine - Red Stringybark - red gum - box low open forest on siliceous rocky outcrops in the NSW South Western Slopes Bioregion | 5,578 |
| 321 | Red Stringybark - Long-leaved Box - Black Cypress Pine shrub/grass woodland on siliceous sedimentary ranges in the upper NSW South Western Slopes and South Eastern Highlands Bioregions | 44 |
| 341 | Blakely's Red Gum - Red Box - Black Cypress Pine grass/shrub woodland on hills in the upper slopes sub-region of the NSW South Western Slopes and western South Eastern Highlands Bioregions | 65 |
| 343 | Mugga Ironbark - Red Box - Red Stringybark - Western Grey Box grass/shrub woodland on metamophic substrates in the Tarcutta - Gundagai region, NSW South Western Slopes Bioregion | 4,187 |
| 346 | White Box - Blakely's Red Gum - White Cypress Pine shrubby woodland on metamorphic hills in the Wagga Wagga - Cootamundra region of the NSW South Western Slopes Bioregion | 4,076 |
| 348 | Red Stringybark - Long-leaved Box - *Rytidosperma pallidum* grassy open forest in the upper Lachlan catchment, NSWSWS and South Eastern Highlands Bioregions | 559 |
| 354 | Red Stringybark - Long-leaved Box - Black Cypress Pine shrub/grass woodland on siliceous sedimentary ranges in the upper NSW South Western Slopes and South Eastern Highlands Bioregions | 44 |
| **Freshwater Wetlands** | | |
| **Inland Floodplain Swamps** | | |
| 12 | Shallow marsh wetland of regularly flooded depressions on floodplains mainly in the semi-arid (warm) climatic zone (mainly Riverina and Murray Darling Depression Bioregions) | 36 |
| 47 | Swamp grassland wetland of the Riverine Plain | 4,605 |
| 53 | Shallow freshwater wetland sedgeland in depressions on floodplains on inland alluivial plains and floodplains | 8 |
| 181 | Common Reed - Bushy Groundsel aquatic tall reedland grassland wetland of inland river systems | 56 |
| 182 | Cumbungi rushland wetland of shallow semi-permanent water bodies and inland watercourses | 312 |
| 238 | Permanent and semi-permanent freshwater lakes wetland of the inland slopes and plains | 16 |
| 335 | Tussock grass - sedgeland fen - rushland - reedland wetland in impeded creeks in valleys in the upper slopes sub-region of the NSW South Western Slopes Bioregion | 125 |
| 336 | Rush - Sedge - Common Reed mainly lentic channel wetland of the Upper Murray and mid-Murrumbidgee River floodplains in the NSW South Western Slopes Bioregion | 111 |
| n/a | Swamp mosaic (some, or all, of NSW VCAs 17, 24, 47, 53, 181, 182 & 999) | 29,085 |
| **Inland Floodplain Shrublands** | | |
| 17 | Lignum shrubland wetland of the semi-arid (warm) plains (mainly Riverina and Murray Darling Depression Bioregions) | 1,082 |
| 24 | Canegrass swamp tall grassland wetland of drainage depressions, lakes and pans of the inland plains | 3,138 |
| 160 | Nitre Goosefoot shrubland wetland on clays of the inland floodplains | 286 |

| ID | NSW VCA Plant Community Type | Hectares |
|---|---|---|
| **Forested Wetlands** | | |
| **Eastern Riverine Forests** | | |
| 85 | River Oak forest and woodland wetland of the NSW South Western Slopes and South Eastern Highlands Bioregions | 252 |
| **Inland Riverine Forests** | | |
| 2 | River Red Gum-sedge dominated very tall open forest in frequently flooded forest wetland along major rivers and floodplains in south-western NSW | 2,204 |
| 5 | River Red Gum herbaceous-grassy very tall open forest on inner floodplains in the lower slopes subregion of the NSW South Western Slopes and Riverina Bioregions | 27,405 |
| 7 | River Red Gum - Warrego Grass - herbaceous riparian tall open forest wetland mainly in the Riverina Bioregion | 3,996 |
| 9 | River Red Gum - wallaby grass tall woodland wetland on the outer River Red Gum zone mainly in the Riverina Bioregion | 7,846 |
| 10 | River Red Gum - Black Box woodland wetland of the semi-arid (warm) climatic zone (mainly Riverina and Murray Darling Depression Bioregions) | 1,304 |
| 11 | River Red Gum - Lignum very tall open forest or woodland wetland on floodplains of semi-arid (warm) climate zone (mainly Riverina and Murray Darling Depression Bioregions) | 55 |
| 79 | River Red Gum shrub/grass riparian tall woodland or open forest wetland mainly in the upper slopes sub-region of the NSW South Western Slopes and western South East Highlands Bioregions | 5,011 |
| 249 | River Red Gum swampy woodland wetland on cowals (lakes) and associated flood channels in central NSW | 3,259 |
| **Semi-arid Woodlands** | | |
| **Inland Floodplain Woodlands** | | |
| 13 | Black Box - Lignum woodland wetland of the inner floodplains in the semi-arid (warm) climate zone (mainly Riverina and Murray Darling Depression Bioregions) | 355 |
| 15 | Black Box open woodland wetland with chenopod understorey mainly on the outer floodplains in south-western NSW (mainly Riverina and Murray Darling Depression Bioregions) | 5 |
| 16 | Black Box grassy open woodland wetland of rarely flooded depressions in south western NSW (mainly Riverina and Murray Darling Depression Bioregions) | 6,470 |
| **North-west Floodplain Woodlands** | | |
| 55 | Belah woodland on alluvial plains and low rises in the central NSW wheatbelt to Pilliga and Liverpool Plains regions | 154 |
| **Riverine Plain Woodlands** | | |
| 26 | Weeping Myall open woodland of the Riverina and NSW South Western Slopes Bioregions | 2,815 |
| **Riverine Sandhill Woodlands** | | |
| 20 | Buloke - Moonah - Black Box open woodland on sandy rises of semi arid (warm) climate zone (mainly Riverina and Murray Darling Depression Bioregions) | 704 |
| 28 | White Cypress Pine open woodland of sand plains, prior streams and dunes mainly of the semi-arid (warm) climate zone | 3,256 |
| 48 | White Cypress Pine - Drooping Sheoak grassy open woodland of the Riverine Plain | 14 |
| 75 | Yellow Box - White Cypress Pine grassy woodland on deep sandy-loam alluvial soils of the eastern Riverina and western NSW South Western Slopes Bioregions | 13,076 |
| **Inland Rocky Hill Woodlands** | | |
| 176 | Green Mallee - White Cypress Pine very tall mallee woodland on gravel rises mainly in the Cobar Peneplain Bioregion | 739 |
| 178 | Broombush - Green Mallee - Blue Mallee very tall shrubland on stony rises in the NSW South Western Slopes Bioregion | 17 |
| 185 | Dwyer's Red Gum - White Cypress Pine - Currawang shrubby woodland mainly in the NSW South Western Slopes Bioregion | 17,201 |
| 186 | Dwyer's Red Gum - Black Cypress Pine - Currawang shrubby low woodland on rocky hills mainly in the NSW South Western Slopes Bioregion | 11,829 |
| 239 | Red Stringybark – Dwyer's Red Gum - Black Cypress Pine woodland on siliceous ranges in the Lockhart to Griffith regions, South Western Slopes and Cobar Peneplain Bioregions | 154 |
| 257 | Dwyer's Red Gum - Currawang grassy low woodland of the central western plains of NSW | 195 |
| 292 | She oak - Fringe Myrtle heathland on rocky ranges in the NSW South Western Slopes Bioregion | 984 |
| 317 | Currawang very tall shrubland on siliceous rocky ridges and cliffs mainly in the NSW South Western Slopes Bioregion | 5,810 |
| 318 | Mugga Ironbark - Tumbledown Red Gum - Red Box - Black Cypress Pine open forest on shallow stony soils on hills in the NSW South Western Slopes Bioregion | 1,470 |
| 319 | Tumbledown Red Gum - White Cypress Pine hill woodland in the southern part of the NSW South Western Slopes Bioregion | 2,176 |
| 634 | White Cypress Pine woodland on hills in the eastern Riverina to western NSW South Western Slopes Bioregions | 702 |
| **Sand Plain Mallee Woodlands** | | |
| 173 | Sandplain mallee of central NSW | 405 |
| 174 | Mallee - Gum Coolabah woodland on red earth flats of the eastern Cobar Peneplain Bioregion | 246 |
| **Semi-arid Sand Plain Woodlands** | | |
| 57 | Belah/Black Oak - Western Rosewood - Wilga woodland of central NSW including the Cobar Peneplain Bioregion | 89 |

| ID | NSW VCA Plant Community Type | Hectares |
|---|---|---|
| **Arid Shrublands** | | |
| **Riverine Chenopod Shrublands** | | |
| 164 | Cotton Bush open shrubland of the semi-arid (warm) zone | 1,958 |
| 216 | Black Roly Poly low open shrubland of the Riverina and Murray-Darling Depression Bioregions | 894 |
| n/a | Shrub mosaic (some, or all, of NSW VCAs 17, 160, 164, 216) | 801 |
| **North-west Plain Shrublands** | | |
| 77 | Yarran shrubland of the NSW central to northern slopes and plains | 69 |
| 229 | Derived mixed shrubland on loamy-clay soils in the Cobar Peneplain Bioregion | 115 |
| **Total Native Vegetation** | | **546,151** |
| **Additional** | | |
| n/a | Native grass with previous cultivation pattern observed on imagery | 3,260 |
| n/a | Native Trees - no NSW VCA plant community [1] | 16 |
| n/a | Commercial plantations (primarily *Pinus radiata*) | 8,629 |
| n/a | Environmental plantings (primarily *Eucalyptus* spp.) | 9,984 |
| n/a | Non-vegetated land and non-native vegetation (including improved pasture, cropping and areas below mapping thresholds which contain native species) | 2,091,669 |

[1] A total of 16 hectares of woody native vegetation was unable to be assigned a NSW VCA plant community type due to high levels of disturbance and the presence of regrowth *Acacia* spp.

with less/nil panchromatic bands. The high spatial accuracy in ADS40 linework delineation and thematic accuracy in identifying plant community types meets a range of user needs such as regional, local and site level environmental assessment including aspects of regulatory compliance.

The detailed vegetation mapping combined with the comprehensive description, threat and protected area assessment of each plant community in the NSW VCA database provides a useful combination of spatial and non-spatial information for land use planning. An advantage of this mapping method over traditional wet film API mapping is that polygon digitising and attribution occurs directly in the digital GIS environment so there is no need for secondary data capture processes that can lead to transfer errors. We found that field reconnaissance to identify NSW VCA plant community types facilitated rapid assessment of multiple attributes of the vegetation and reduced errors in coding of plant communities in the map polygons. Since DAPI operators and botanists were able to view ADS40 images in a 3-D environment simultaneously, this lead to group discussion and increased map attribution consistency.

### *Grassland mapping*

In western parts of the study area the detail within the ADS40 imagery and the use of zoom functions in the GIS environment allowed DAPI operators to confidently distinguish between low chenopod shrublands and grassland communities. When occurring in a natural / ungrazed state, tall grasslands, such as NSW VCA 45 [Plains Grass grassland on alluvial mainly clay soils in the Riverina and NSW South-western Slopes Bioregions] could be separated from low grasslands, such as NSW VCA 44 [Forb-rich Speargrass – Windmill Grass – White Top grassland of the Riverina Bioregion]. However, delineation between low grasslands such as NSW VCA 44 and NSW VCA 46 [Curly Windmill Grass – speargrass – wallaby grass grassland on alluvial clay and loam on the Hay Plain, Riverina Bioregion] was less certain due to high structural similarities. Low grasslands were delineated with high confidence at times, and such delineation would have been improved if additional resources were allocated to field reconnaissance and mapping time. While the technology shows much capability in this area, accurate delineation of structurally similar non-woody vegetation types, requires a level of reconnaissance beyond the scope of this study, or a reliance on vast amounts of existing vegetation plot data presenting strong correlations with accurate edaphic datasets. This was not available for the parts of the study area where these vegetation types occur. As a result, the majority of natural grasslands were mapped as 'Native Grassland Mosaic'. The ADS40 imagery used for this study was captured after eight to ten years of severe drought, and much of the reconnaissance was undertaken during drought conditions. Therefore, it is likely that the limitation of mapping mosaics would be alleviated if ADS40 image capture and field reconnaissance were synchronised during times of vigorous vegetative growth, or additional resources were allocated to field reconnaissance and mapping time.

Differentiating between natural and derived grasslands within the 'native grassland mosaic' mapped type was not considered in the original study design. As such, the 'native grassland mosaic' contains a combination of natural and derived grasslands. It is considered that grasslands within the Riverina bioregion are likely to be natural in origin (primarily NSW VCA 44, 45 & 46), with derived grasslands primarily being NSW VCA 165. The majority of native grasslands in the South Western Slopes bioregion are derived primarily from plant communities occurring in grassy woodland formations. Some areas mapped as 'native grassland mosaic' in the Riverina bioregion may be derived from NSW VCA 26 [*Weeping Myall open woodland of the Riverina and NSW South Western Slopes bioregion*].

### *Woodland and open forest mapping*

With the exception of non-woody vegetation types with similar structure (e.g. native grasslands), the NSW VCA plant community types were able to be accurately delineated in this study. However, at times there was some difficulty in the polygon attribution of NSW VCA plant community types on hill mosaics in the Upper Slopes subregion of the South Western Slopes bioregion. This was due to the overlap of canopy species between compositionally similar NSW VCA plant community types with broad ecotonal boundaries (e.g. (NSW VCA 289 and 291 on the Tarcutta 1:100,000 mapsheet).

An issue with some vegetation type maps has been the ability to consistently delineate between open woodland and non-woody vegetation at ecotonal boundaries. In this study the delineation between non-woody and open woodland environments was set at 5% crown cover (or a crown separation ratio of 3:1 (Penridge & Walker 1988). However, when mapping in a digital environment there is potential to provide quantitative assessment of crown separation ratio in a GIS platform. For instance, in recent years technological advances have seen the development of 'tree canopy layers' to spatially represent the presence of woody vegetation (e.g. Roff et al. 2010, Roff & Davies 2011). Such products provide a level of guidance as to the presence of woody vegetation including scattered and isolated paddock trees. Digitally displaying the relative distance between tree crown edges provides an opportunity to utilise the digital environment to provide a consistent on-screen guide when delineating between woodland and non-woody vegetation. One option of quantifying this delineation is to develop zonal statistics models from tree canopy layers to quantify crown separation ratio.

### *Independent Accuracy Assessment*

The independent validation of the accuracy of the vegetation map product provides a level of confidence for the end-user of the vegetation map. While there are a number of methods for developing comprehensive, efficient and statistically valid sampling stratifications to guide vegetation surveys (refer to Neldner et al. 1995), these are generally aimed at guiding sampling strategies to collect new survey data, or to confidently classify assemblages of plants. Although the concept of validating the accuracy of vegetation maps is discussed in some literature (e.g. Gopal & Woodcock 1994, Townsend 2000), appropriate sampling adequacy guidelines to determine accuracy of polygon-based vegetation maps are yet to be developed relative to landscape heterogeneity, and as such the true adequacy of the validation can only be inferred by the number of blind field validation plots analysed in this study.

Independent assessors undertook a blind stratification process based on the native vegetation footprint of each NSW Landscape (Mitchell 2003). This resulted in some plant community types with small distributions in the study area having limited samples. In order to present the independent accuracy assessment data in a meaningful way, it was necessary to present the plant community type accuracy levels at a NSW Class level (as per Table 8). There are significant resources required in collecting independent field validation data and it has rarely been done to the levels undertaken here, however improvements could be made for future mapping projects by developing a sampling stratification based on a blind delineation of the study area using a finer scale stratification such as plant community types.

While accuracy was validated by direct point comparison it could be improved by considering levels of error in delineating vegetation polygon boundaries, separate validation botanists having similar interpretive understanding of NSW VCA plant communities and increased checking on private land. Additionally, it is reasonable to accept that, even at a capture scale of circa 1:4,000, a vegetation polygon boundary may have an error of approximately 5–10 metres. In considering an error level of 10 metres in the accuracy assessment analysis, it is possible that the user accuracy level may increase through enabling field validation plots that occur

**Table 8. User accuracy of NSW VCA plant community types, categorised by NSW Vegetation Class (Keith 2004) with number of replicate samples in brackets.**

| **NSW Vegetation Class** | **User Accuracy of Plant Community Types within NSW Vegetation Class** | |
|---|---|---|
| Eastern Riverine Forests | 100 % | (2) |
| Floodplain Transition Woodlands | 87 % | (354) |
| Inland Floodplain Shrublands | 100 % | (3) |
| Inland Floodplain Swamps | 55 % | (11) |
| Inland Floodplain Woodlands | 96 % | (23) |
| Inland Riverine Forests | 95 % | (97) |
| Inland Rocky Hill Woodlands | 77 % | (48) |
| North-west Plain Shrublands | 100 % | (1) |
| Riverine Chenopod Shrublands | 100 % | (2) |
| Riverine Plain Grasslands | 96 % | (90) |
| Riverine Plain Woodlands | 92 % | (13) |
| Riverine Sandhill Woodlands | 75 % | (57) |
| Sand Plain Mallee Woodlands | 100 % | (3) |
| Southern Tableland Grassy Woodlands | 100 % | (3) |
| Upper Riverina Dry Sclerophyll Forests | 72 % | (32) |
| Western Slopes Dry Sclerophyll Forests | 87 % | (74) |
| Western Slopes Grassy Woodlands | 87.3% | (228) |
| **Overall User Accuracy** | **87 %** | **(1041)** |

Sources: EcoLogical (2009, 2010, 2011a, 2011b), GHD (unpub.), SKM (2009) in this ten metre error zone to be assigned to the adjacent polygon.

Polygon attribution to NSW VCA plant community type, undertaken by DAPI operators, was based on whole of polygon observations of dominant species observed on the imagery and their position in the landscape. Such ecological community polygon-scale observations do not always correlate with that of fine-scale quadrat observations. For this study, independent field validation plots were based on 50 x 50 metre plot observations (plus viewshed within the same apparent NSW VCA type), which at 0.25 hectares is below the one hectare specification for minimum polygon size in this study. In some instances a polygon may be considered incorrect based on such fine-scale observations within a broader polygon. The same is true when deciding between similar vegetation types within broad ecotones, or between NSW VCA plant community types which are compositionally similar. The method described by Gopal & Woodcock (1994) helps to address this by allowing for 'levels of correctness'.

### *Map application flexibility*

Development of a vegetation map capturing multiple attributes such as those collected as part of this study enhances uses of the vegetation map product. For example, Modelling the distribution of polygons containing *Allocasuarina verticillata* as a dominant species can give a strong indication of potential feed areas for the glossy black-cockatoo (*Calyptorhynchus lathami*), a cockatoo which favours foraging habitat with an abundance of Casuarina (Cameron 2007, Higgins et al. 1999).

Modelling the distribution of polygons attributed to a NSW VCA plant community type containing Eucalyptus camaldulensis, coupled with polygons attributed to good crown health can give a strong indication of Eucalyptus camaldulensis forests with relatively healthy hydrological function.

Modelling the distribution of the critically endangered community White Box grassy woodland in the upper slopes sub-region of the NSW South Western Slopes Bioregion (NSW VCA 266) containing woody regrowth can indicate remnants with regrowth of key woody species. Multiple attribute vegetation mapping has the potential to greatly reduce site assessment costs for some conservation and planning programs such as:

- *Landscape-scale conservation including reserve acquisition, regional conservation planning, targeted conservation investment, threatened species, and other habitat modelling and landscape restoration;*
- *Property vegetation planning;*
- *Private native forestry assessments;*
- *Native vegetation compliance assessments;*
- *Biobanking assessments;*
- *Biodiversity certification for local councils;*
- *Monitoring, evaluation and reporting; and*
- *Fire behaviour modelling.*

The detailed mapping developed in this study should form a basis for monitoring change over coming decades and we encourage management authorities to use the data for conservation planning, vegetation and environmental restoration projects with the aim to protect biodiversity and improve the extent and condition of native vegetation in the region.

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## Downloadable Appendices

**Folder 1:** NSW VCA database plant community type descriptions

**Folder 2:** PDF format vegetation maps for each of nine 1:100,000 and three 1:50,000 map tiles in the study area.

Note: GIS format data of this mapping can be obtained under licence by emailing data.broker@environment. nsw.gov.au or downloading VIS product '3884' from http://mapdata.environment.nsw.gov.au/DDWA/.

## References

Adamson C. L. & Loudon A. G. (1966) Wagga Wagga 1:250 000 Geological Sheet SI/55–15. 1st edition, Geological Survey of New South Wales, Sydney.

Anderson, R.H. (1961) Introduction. flora series Nos. 1–18: 1–16. *Contributions from the New South Wales National Herbarium.* Royal Botanic Gardens: Sydney.

Allard, A., Nilsson, B., Pramborg, K.,, Ståhl, G., & Sundquist, S. (2003) Manual for aerial photo interpretation in the National Inventory of Landscapes in Sweden. Department of Forest Resource Management and Geomatics, Sveriges lantbruksuniversitet (Swedish University of Agricultural Sciences), Umeå.

Beadle, N.C.W. & Costin, A.B. (1952) Ecological classification and nomenclature. *Proceedings of the Linnean Society of New South Wales* 67: 61–82.

Bedward, M., Ellis, M. & Gleeson, P. (2011) YETI version 3.2.27. Yet Another Vegetation Survey Database. NSW National Parks and Wildlife Service, Compiled 11th March 2011.

Benson, J. S. (2006) New South Wales Vegetation Classification and Assessment: Introduction – the classification, database, assessment of protected areas and threat status of plant communities. *Cunninghamia* 9(3) 331–382.

Benson, J.S. (2008) New South Wales Vegetation Classification and Assessment: Part 2 Plant communities in the NSW South-western Slopes Bioregion and update of NSW Western Plains plant communities. Version 2 of the NSW VCA database. *Cunninghamia* 10(4): 599–673.

Benson, J.S., Ashby, E.M. & Porteners, M.F. (1997) The native grasslands of the Riverine Plain, New South Wales. *Cunninghamia* 5(1): 1–48

Benson, J.S., Allen, C., Togher, C. & Lemmon, J. (2006) New South Wales Vegetation Classification and Assessment: Part 1 Plant communities of the NSW Western Plains. *Cunninghamia* 9(3): 383–451.

Benson, J.S., Richards, P.G., Waller, S. & Allen, C.B. (2010) New South Wales Vegetation Classification and Assessment: Part 3 Plant communities of the NSW Brigalow Belt South, Nandewar and west New England Bioregions and undate of the NSW Western Plains and South-western Slopes plant communities. Version 3 of the NSW VCA database. *Cunninghamia* 11(4): 457–579.

Black, J. & Peasley, B. (2008) Digital Airborne Imagery Fact Sheet. Unpublished Report. Information Sciences Branch, NSW Department of Environment and Climate Change, Grafton.

BoM (2011) Climatic Statistics. [URL: http://www.bom.gov.au/climate/]. Bureau of Meterology. Website Accessed 17 October 2011.

Bos, D. & Lockwood, M. (1996) Flora, fauna and other features of the south west slopes biogeographic region, NSW. Report No. 59, Johnson Centre of Parks, Recreation and Heritage. Charles Sturt University: Albury.

Bowen, S. & Simpson, S.L. (2009) Changes in extent and condition of the vegetation communities of the Gwydir wetlands and floodplain 1996–2008. Report for the NSW Wetland Recovery Program. NSW Department of Environment and Climate Change: Sydney.

Bradter, U., Thom, T.J., Altringham, J.D., Kunin, W.E. and Benton, T.G. (2011) Prediction of National Vegetation Classification communities in the British uplands using environmental data at multiple spatial scales, aerial images and the classifier random forest. *Journal of Applied Ecology* 48: 1057–1065.

Brickhill, J. (1985) Vegetation by geographic region: Southern Riverina. Paper No. 13. Review of Nature Conservation Programs. Unpublished. NSW National Parks and Wildlife Service: Sydney.

Cameron, M. (2007) *Cockatoos*. Collingwood, VIC, Australia: CSIRO Publishing.

DEC (2006) Reconstructed and extant distribution of native vegetation in the Lachlan Catchment. NSW Department of Environment and Conservation, Dubbo.

DECC (2007) The native vegetation of the southern wheat-sheep belt. NSW Department of Environment and Climate Change, June 2007.

DECC (2008) Biobanking assessment methodology. NSW Department of Environment and Climate Change, Sydney.

DECCW (2011) Operational manual for BioMetric 3.1. Department of Environment, Climate Change and Water, NSW. Sydney.

DEH (2000) Revision of the Interim Biogeographic Regionalisation of Australia (IBRA) and the development of version 5.1. Summary Report. Department of Environment and Heritage, Canberra.

DERM (2011) Certified regional ecosystem map for the purpose of the Vegetation Management Act 1999. Version 6. Online RE Maps, The Department of Environment and Resource Management, Brisbane. [URL: http://www.derm.qld.gov.au/REMAP]. Website Accessed 21st October 2011.

DSE (2011) Biodiversity interative map. The state of Victoria, Department of Sustainability and Environment. [URL: http://mapshare2.dse.vic.gov.au/MapShare2EXT/imf.jsp?site=bim]. Website Accessed 27th October 2011.

DUAP (2000) CRAFTI southern report: a project undertaken as part of the NSW Comprehensive Regional Assessments . Department of Urban Affairs and Planning, Sydney.

EcoGIS (2004) Mapping of vegetation ecosystems in new and existing conservation reserves, South West Slopes Region, 2002–2004. Version 2. Report to the NSW National Parks and Wildlife Service, South West Slopes Region.

EcoLogical (2009) Field verification of vegetation mapping on the "Narrandera" Group of mapsheets on the South West Slopes of NSW: accuracy assessment of mapping undertaken using the 'Vegetation Classification and Assessment (VCA)' classification. An unpublished report to the NSW Department of Environment and Climate Change.

EcoLogical (2010) Field verification of vegetation mapping on the Urana and Lockhart 1:100,000 mapsheets on the South West Slopes of NSW: accuracy assessment of mapping undertaken using the 'Vegetation Classification and Assessment (VCA)' classification. 16 May 2010. An unpublished report to the NSW Department of Environment and Climate Change.

EcoLogical (2011a) Field validation of vegetation mapping on the Tarcutta 1:100,000 mapsheet: accuracy assessment of mapping undertaken using the 'Vegetation Classification and Assessment (VCA)' classification. A Report Prepared by EcoLogical Pty. Ltd. for the Office of Environment and Heritage, Queanbeyan. July 2011.

EcoLogical (2011b) Field validation of vegetation mapping on the Yanco 1:100,000 mapsheet and Yoogali 1:50,000 mapsheet: accuracy assessment of mapping undertaken using the 'Vegetation Classification and Assessment (VCA)' classification. A Report Prepared by EcoLogical Pty. Ltd. for the Office of Environment and Heritage, Queanbeyan. July 2011.

ERDAS (2010) ERDAS production suite for ArcGIS – Stereo Analyst, FeatureAssist and ERDAS Terrain Editor. [URL: http://www.erdas.com/Libraries/Brochures/ERDAS_Production_Suite_for_ArcGIS_Brochure.sflb.ashx]. Website Accessed 21st October 2011.

ESRI (2011) *ArcGIS*. [URL: http://www.esri.com/software/arcgis/index.html]. Website Accessed 21st October 2011.

Faber-Langendoen, D., Aeseng, N., Hop, K., Lew-Smith, M. and Drake, J. (2007) Vegetation classification, mapping and monitoring at Voyageurs National Park, Minnesota: An application of the U.S. National Vegetation Classification. *Applied Vegetation Science* 10: 361–374.

Gellie, N. J. (2005) Native vegetation of the Southern Forests: South-east highlands, Australian Alps, South-west Slopes and South-east Corner bioregions. *Cunninghamia* 9(2): 219–253.

GHD (unpublished) Independent field validation data to determine the accuracy of vegetation mapping on the Wagga Wagga 1:100,000, Berembed Weir and Coolamon 1:50,000 mapsheets. Unpublished data collected by GHD Wagga Wagga for the NSW Department of Environment, Climate Change and Water, Queanbeyan. May 2010.

Gibbons, P. & Boak, M. (2002) The importance of paddock trees for regional conservation in agricultural landscapes. *Ecological Management and Restoration* 3(3): 205–210.

Gibbons, P., Ayers, D., Seddon, J., Doyle, S. & Briggs, S. (2005) BioMetric Version 1.8. A Terrestrial Biodiversity Assessment Tool for the NSW Property Vegetation Plan Developer. Operational Manual. NSW Department of Environment and Conservation, unpublished.

Gopal, S. & Woodcock, C. (1994) Theory and methods for accuracy assessment of thematic maps using fuzzy sets. *Photogrammetric Engineering and Remote Sensing* 60(2): 181–188.

Grossman, D.H., Faber-Langendoen, D., Weakley, A.S., Anderson, M., Bourgeron, P., Crawford, R., Goodin, K., Landaal, S., Metzler, L., Patterson, K.D., Pyne, M., Reid, M. & Sneddon, L. (1998) International classification of ecological communities: terrestrial vegetation of the United States. Volume I. The National Vegetation Classification System: development, status, and applications. The Nature Conservancy: Arlington, Virginia, USA.

Hastedt, H.; Ginzler, C.; Meile, R., (2009a) GIS-gestützte 3D-Luftbildinterpretation im Landesforstinventar der Schweiz. *Geomatik Schweiz* 107, 12/2009: 596–599.

Hastedt, H., Meile, R. & Ginzler, C., (2009b) ArcGIS applikation zur 3D datenerfassung im landesforstinventar der Schweiz. In: Strobl, J.; Blaschke, T.; Griesebner, G. (eds) Angewandte Geoinformatik 2009. Beiträge zum 21. AGIT-Symposium Salzburg. Heidelberg, Herbert Wichmann. 8–13.

Heiskanen, J., Nilsson, B., Mäki, A., Allard, A., Moen, J., Holm, S., Sundquist, S. and Olsson, H. (2008) Aerial photo interpretation for change detection of treeline ecotones in the Swedish mountains. *Arbetsrapport* 242 2008. Institutionen för skoglig resurshushållning (Institute for Forest Research) Sveriges lantbruksuniversitet (Swedish University of Agricultural Sciences), Umeå.

Hennessy, K., McInnes, R., Abbs, D., Jones, R., Bathols, D., Suppiah, R., Ricketts, J., Rafter, T., Collins, D. & Jones, D. (2004) Climate change in New South Wales. Part 2: Projected changes in climate extremes. Consultancy Report to New South Wales Greenhouse Office by Climate Impact Group CSIRO Atmospheric Research and National Climate Centre (Australian Government Bureau of Meteorology: Melbourne).

Higgins, P.J., Al-Dabbagh, K.Y., Bartram, K., Considine, M., Cowling, S.J., Davies, S. J. J. F., Debus, S. J. S., Dunn, A. M., Easdes, D. W., James, D. J., Howard, T., Lansley, P. S., Myers, C. M., Peter, J. M., Price, G. D., Pywell, S. R., Rogers, D. I., Starks, J. R. & Weston, M. A. eds. (1999) *Handbook of Australian, New Zealand and Antarctic birds. Volume 4 – Parrots to Dollarbirds*. Oxford University Press: South Melbourne.

Keith, D.A. (2004) *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT.* Department of Environment and Conservation (NSW), Hurstville.

Keith, D.A. & Bedward, M. (1999) Native Vegetation of the South East Forests Region, Eden, New South Wales. *Cunninghamia* 6: 1–218.

Leica Geosystems (2004) ADS40 large-scale digital imagery. [URL: http://www.dlr.de/os/Portaldata/48/Resources/ dokumente/ ads40_flyer_leica.pdf]. Website Accessed 19th December 2011.

Maguire, O., Thomas, V. & Hunter, S. (2000) Southern Comprehensive Regional Assessment – Riverina Highlands vegetation mapping extension. A report undertaken by the National Parks and Wildlife Service Comprehensive Regional Assessment Unit for the Riverine Highlands Regional Vegetation Management Committee.

McDougall, K. (2008) Evidence for the natural occurrence of treeless grasslands in the Riverina region of south-eastern Australia. *Aust. J. Botany* 56: 461–468.

Mitchell, P.B. (2003). NSW ecosystems database mapping unit descriptions. Unpublished report to the NSW National Parks and Wildlife Service, Hurstville.

Moore, C.W.E. (1953) The vegetation of the south-eastern Riverina, New South Wales 1: the climax communities. *Aust. J. Botany* 1: 485–547.

Neldner, V.J., Crossley, D.C. & Cofinas, M. (1995) Using Geographical Information Systems (GIS) to determine the adequacy of sampling in vegetation surveys. *Biological Conservation* 73: 1–17.

NGH Environmental (2008) Proposed development of Stage 1, Silverton Wind Farm, far western New South Wales. biodiversity assessment. NGH Environmental, Bega.

NPWS (2001) New South Wales South West Slopes bioregion scoping study. A draft report prepared for the NSW Biodiversity Strategy. NSW National Parks and Wildlife Service, June 2001.

NPWS (2003) The bioregions of New South Wales: their biodiversity, conservation and history. NSW National Parks and Wildlife Service, Hurstville.

OEH (unpublished a) Vegetation Information System: Classification. [URL: http://www.environment.nsw.gov.au/ research/Visclassification.htm]. Office of Environment and Heritage, Department of Premier and Cabinet (NSW). Website Accessed 14 June 2012.

OEH (unpublished b) *BioMetric* Vegetation Types. [URL: http:// www.environment.nsw.gov.au/projects/ BiometricTool.htm]. Office of Environment and Heritage, Department of Premier and Cabinet (NSW). Website Accessed 17 October 2011.

Parkes, D., Newell, G. & Cheal, D. (2003) Assessing the quality of native vegetation: the ‘habitat hectares’ approach. *Ecological Management and Restoration* Volume 4 Supplement: s29–s38. February 2003.

Penridge, L.K. & Walker, J. (1988) The crown-gap ration (C) and cover percent. 2. Studies of the properties of C. *Aust. J. Ecol.* 13: 109–120.

Planar (2011*)* 3-D Applications. [URL: http://www.planar3d. com/3d-applications/]. Website Accessed 21st October 2011.

Porteners, M.F. (2001) Vegetation survey of Ingalba, Big Bush and Pucawan Nature Reserves. Report for NSW National Parks and Wildlife Service: Riverina Region.

Porteners, M.P. (2007) Native vegetation of Koorawatha, Dananbilla, Illunie and Gungewalla Nature Reserves. Report to DECC NSW, Southern Office: Queanbeyan.

Porteners, M.F. (2011) Vegetation survey of Cobbora State Conservation Area. Report to NSW Department of Environment, Climate Change and Water.

Priday, S. (2006) The biolandscapes of the New South Wales South-western Slopes Bioregion (Lachlan, Murrumbidgee and Murray Catchments). Unpublished report to Department of Environment and Conservation, South Branch: Queanbeyan.

Priday, S. & Mulvaney, M. (2005) The native vegetation and threatened species of the City of Wagga Wagga. Department of Environment and Conservation, Queanbeyan, NSW.

Queensland Herbarium (2003) Regional ecosystem description database (REDD). A database describing regional ecosystems. Environmental Protection Agency, Brisbane. http://www. derm.qld.gov.au/wildlife-ecosystems/biodiversity/regional_ ecosystems/

Roberts, I. & Roberts, J. (2001) Plains wanderer (*Pedionomus torquatus*) habitat mapping: including woody vegetation and other landscape features. Riverina plains, NSW. A report prepared by Earth Resources Pty. Ltd. For the NSW National Parks and Wildlife Service – March 2001.

Roff, A. & Davies, K. (2011) Woody vegetation of the ACT: crown scale segmentation of SPOT5. Unpublished Report. NSW Department of Environment, Climate Change and Water, Sydney.

Roff, A., Sivertsen, D. & Denholm, B. (2010) The Native Vegetation of the Murray Catchment Management Authority Area. Unpublished report. NSW Department of Environment, Climate Change and Water, Sydney.

Sattler, P.S. & Williams, R.D. (1999) (eds.) The Conservation Status of Queensland's Bioregional Ecosystems. Environmental Protection Agency: Brisbane.

SKM (2009) Field validation of vegetation mapping of the South-Western Slopes of NSW: Cootamundra and Junee mapsheets. Unpublished report prepared by Sinclair Knight Merz for the NSW Department of Environment, Climate Change and Water, October 25, 2009.

Sivertsen, D. (2009) Native Vegetation Interim Type Standard. Department of Environment, Climate Change and Water NSW, Sydney.

Thackway, R. & Cresswell, I.D. (1995) An interim biogeographic regionalisation for Australia: a framework for setting priorities in the national reserves system cooperative program. Australian Nature Conservation Agency, Canberra.

Townsend, P.A. (2000) A quantitative fuzzy approach to assess mapped vegetation classifications for ecological applications. *Remote Sensing of Environment* 72: 253–267.

Tozer, M.G., Turner, K., Keith, D.A., Tindall, D., Pennay, C., Simpson, C., MacKenzie, B., Beukers, P. & Cox, S. (2010) Native vegetation of southeast NSW: a revised classification and map for the coast and eastern tablelands. *Cunninghamia* 11 (3): 359–406.

Tuckwell K. D. (1976) Jerilderie 1:250 000 Geological Sheet SI/55–14. 2nd edition, Geological Survey of New South Wales, Sydney.

Victorian Department of Natural Resources (2001) Descriptions of Ecological Vegetation Classes of Victoria. Unpublished working document. Department of Natural Resources, Melbourne.

Walker, J., & Hopkins, M.S. (1990) Vegetation. In: McDonald, R.E., Isbell, R.F., Speight, J.R., Walker, J. & Hopkins, M.S. eds. (1990) *Australian soil and land survey field handbook*, *2nd edition,* pp. 58–77. Inkata Press, Melbourne and Sydney.

Warren, A. Y. F., Gilligan, L. B. & Raphael, N. M. (1996) Cootamundra 1:250 000 Geological Sheet SI/55–11. 2nd edition, Geological Survey of New South Wales, Sydney.

Webster, M. & Turner, R. (2007) A review of high-resolution remote sensing options for foresters. A paper presented at the 2007 Australian & New Zealand Institutes of Foresters Conference, Coffs Harbour, NSW. Institute of Foresters Australia.

Webster, M. (2008) 'Stereo Analyst for ArcGIS Procedures: Version 1. Unpublished. Forests NSW. 32pp.

Westbrook, M., Gowans, S. & Gibson, M. (2011) The vegetation of Coonavitra area, Paroo Darling National Park, western new South Wales. *Cunninghamia* 1291): 7–28.

White, M.D., Muir, A.M. & Webster, R. (2002) The reconstructed distribution of indigenous vegetation types across the NSW Riverina. Draft report to the NSW National Parks and Wildlife Service.

Whiting, E. (2006) Vegetation survey of The Rock Nature Reserve. Report for NSW National Parks and Wildlife Service: Riverina Region.

Wynn D. W. (1977) Narrandera 1:250 000 Geological Sheet SI/55–10. 2nd edition, Geological Survey of New South Wales, Sydney.

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# Vegetation, fauna and groundwater interrelations in low nutrient temperate montane peat swamps in the upper Blue Mountains, New South Wales

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***Abstract***: Newnes Plateau Shrub Swamps are a series of low nutrient temperate montane peat swamps around 1100 m elevation in the upper Blue Mountains, west of Sydney (lat 33° 23' S; long 150° 13' E). Transect-based vegetation studies show a closely related group of swamps with expanses of permanently moist, gently sloping peatlands. Vegetation patterns are related to surface hydrology and subsurface topography, which determine local peat depth. While there is evidence that a group of the highest elevation swamps on the western side of the Plateau are more dependent on rainwater, the majority of swamps, particularly those in the Carne Creek catchment, and east and south of it, may be considered primarily groundwater dependent with a permanently high watertable maintained by groundwater aquifers. An integral part of the swamps are a number of threatened groundwater dependent biota (plants–*Boronia deanei* subsp. *deanei, Dillwynia stipulifera,* dragonfly– *Petalura gigantea,* lizard– *Eulamprus leuraensis*), which are obligate swamp dwellers. This association of dependence leaves the entire swamp ecosystem highly susceptible to threats from any loss of groundwater, the current major one being the impact of damage to the confining aquicludes, aquitards, aquifers and peat substrates as a result of subsidence associated with longwall mining. Impacts on the swamps may also result from changes to hydrology through damming of creeks, mine waste water discharge, increased moisture competition from pine plantations, recreational motorbike and off-road vehicle tracks and climate change.

If these groundwater dependent ecosystems do not receive protection from activities such as longwall mining subsidence, significant ecological damage is unlikely to be avoided or able to be mitigated even where provisions of the Commonwealth *Environment Protection and Biodiversity Conservation* and NSW *Threatened Species Conservation* Acts apply to groundwater dependent swamps and biota. The importance of the highest elevation part of the Plateau for a number of restricted (some endemic) plant species is also discussed.

Keywords: Newnes Plateau Shrub Swamps; Blue Mountains; vegetation patterns; peat swamps; fauna; groundwater dependent; threatened species

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## Introduction

Wetlands encompass a range of vegetated ecosystems, including those referred to as marshes, swamps, bogs and fens (Mitsch & Gosselink 2007; Mitsch *et al.* 2009). These systems are characterised by a diversity of hydrological regimes, and may be permanently, seasonally or intermittently inundated or waterlogged, and may also include ephemeral wetlands (DECCW 2010a). Wheeler (1999) noted that even in permanent wetlands, water table depth could vary considerably within a particular wetland and between different permanent wetland types. Such spatial heterogeneity, even within a permanent wetland complex, may result in considerable heterogeneity in vegetation associations and habitat, often across small spatial scales (e.g. Clarke & Martin 1999; Jabłońska *et al.* 2011; Keith & Myerscough 1993; Keith *et al.* 2006). For example, wetland complexes are often characterised by a complex intergrading of fens, bogs, swamps or marshes (Hájek *et al.* 2006; Kirkpatrick & Bridle 1998; Mitsch & Gosselink 2007; Wheeler & Proctor 2000; Yabe & Onimaru 1997), occasionally with dramatic changes in pH and vegetation characteristics at very small spatial scales (e.g. Brown *et al.* 1982).

Mires (peat-forming wetlands) include bogs and fens (Gore 1983; Moore 2002), although the terms are applied somewhat differently in the Australasian context (Whinam & Hope 2005). In New South Wales, mire ecosystems are captured within the Coastal Heath Swamps, and Alpine– and Montane Bogs and Fens vegetation classes of Keith (2004). In the Blue Mountains region in the Central Tablelands west of Sydney, these are represented by a number of mire vegetation types including Blue Mountains Sedge Swamps (BMSS), Newnes Plateau Shrub Swamps (NPSS) and Boyd Plateau Bogs, which are characterised by considerable spatial heterogeneity across a number of environmental gradients within and between individual swamps and swamp types (e.g. Holland *et al*. 1992a; Holland *et al*. 1992b). Variation in vegetation across the hydrological gradient (from ephemeral to permanent waterlogging) is particularly evident within the upland swamps developed on sandstone geology, including those of the Newnes Plateau.

The sandstone soils of the Blue Mountains were not suited for agricultural developments in the 19th century and the Newnes Plateau north of Lithgow remained virtually undisturbed until the building of the railway to the shale mines at Newnes in the adjacent Wolgan Valley in the early 20th century. Other developments on the Newnes Plateau later in the 20th century were underground coal-mining (bord and pillar method) north from Lithgow and extensive clearing for pine planting during the 1970s in Newnes State Forest in the centre of the Plateau. Recent developments since 1980 have increased fragmentation of vegetation on the Plateau.

The Newnes Plateau Shrub Swamps (NPSS) were first formally recognised in the 1980s and reports of their scientific conservation values were presented to government boards of inquiry on proposed coalmining and electricity generation projects at that time (e.g. Benson 1981). These projects would have destroyed major swamps in the Carne Creek catchment, but despite project approval, a major proposal, the Birds Rock Coal Mine and Washery and associated railway did not go ahead. Information on the scientific importance and distribution of the swamps was subsequently included in the broad scale vegetation mapping of the Wallerawang 1:100 000 map sheet (Benson & Keith 1990) and in more detail in 2005 (DEC 2006).

The construction of the Newnes shale railway in 1906–7 had little direct impact on the landscape (it ceased use in the 1930s), though one of its tunnels has become an important site for glow worms *Arachnocampa richardsae* (Diptera). However, during its construction a number of plant collections were made by the chief engineer and amateur botanist, Henry Deane. His collections included the type specimens of *Boronia deanei,* collected in 1906, commenting– “There are acres of it, to the exclusion of almost any other plant.” (Maiden & Betche 1906). It was recollected in Happy Valley Springs swamp in November 1981 and is now listed as a Vulnerable species under the NSW *Threatened Species Conservation Act* 1995 (TSC Act) because of its limited distribution and restriction to swamp habitat. The occurrence of other restricted swamp plants (e.g. *Dillwynia stipulifera, Olearia quercifolia, Celmisia longifolia*) also became evident in the 1980s following the period of active botanical field exploration. As well, threatened mire-dependent fauna species have been recorded from these swamps, including the Endangered giant dragonfly *Petalura gigantea*, first recorded in NPSS in 2004 (Baird 2012), and the Endangered Blue Mountains water skink *Eulamprus leuraensis*, first recorded in NPSS in 1979 (NSW Wildlife Atlas).

As a result of increasing evidence of the value of the swamps and of increasing threats, *Temperate Highland Peat Swamps on Sandstone* (THPSS) were listed as an Endangered Ecological Community (EEC) under the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (*EPBC* Act) in 2005 (TSSC 2005). Emphasis was placed on their restricted distribution and the impact of threats from introduced animals, increased fertiliser runoff, residential development, clearing, weeds, fire and peat mining. The listing was broad and included swamps occurring along the eastern tablelands of NSW from the Blue Mountains south to Bombala and included swamps in the upper Blue Mountains, and on the Newnes Plateau north of Lithgow. At about the same time, the swamps on the Newnes Plateau were also listed as an EEC under the TSC Act by the NSW Scientific Committee (2005) as the *Newnes Plateau Shrub Swamps in the Sydney Basin Bioregion* EEC.

Developments on the Newnes Plateau now include exotic pine plantations, native forestry logging, sand quarries, coal mines and small-scale rural holdings, in some cases located immediately adjacent to the swamps or separated by narrow buffer strips. Swamps are threatened by small-scale clearing, fragmentation, erosion and sedimentation (all associated with road works), quarrying and periodic timber harvesting from adjacent plantations. Changes to drainage and moisture conditions in some swamps are caused by damming of swamp watercourses; road crossings of swamps;

sedimentation and erosion associated with roadways, quarries, mines and plantation harvesting within swamp catchments; and disposal of waste water from underground coal mines. Considerable ongoing damage to swamps is also occurring as a result of unregulated trail bikes and off-road recreation vehicles. In addition, mine de-watering discharges into headwater streams and swamp systems has occurred across this area causing substantial degradation. Alteration to the natural flow regimes of rivers, streams, floodplains and wetlands is listed as a *Key threatening Process* under the *TSC* Act (NSW Scientific Committee 2002). Invasion of exotic species, including species of *Pinus*, and changes to fire regimes may pose threats to NPSS in future, especially if these processes result in physical displacement of vegetation, increased influx of sediments and/or nutrients, or significant drying of the swamps.

Extractable coal seams at varying depths underlie the Newnes Plateau and underground longwall and board and pillar mining is currently occurring, or proposed to occur, beneath the majority of the listed swamps. Subsidence of the land surface, and associated fracturing of bedrock, occurs after longwall coalmining, and this may change the hydrology of catchments and swamps they contain (NSW Scientific Committee 2005). Specifically, the conversion of perched water table flows into subsurface flows through mine-related voids may significantly alter the water balance of upland swamps (Young & Wray 2000). Changes to surface morphology within or near the swamps as a result of mine subsidence may also create nick points, which become the focus of severe and rapid erosion (Young 1982). Unlike impacts of some of the above threats (such as damming, *Pinus* invasion and road crossings), which may be reversed to some extent, changes which alter subsurface flows and catchment hydrology pose intractable threats to the persistence and integrity of the swamp community. Longwall mining has been listed as a Key Threatening Process under the *TSC Act* 1995 (NSW Scientific Committee 2005) and there has been clear evidence of subsurface damage to some swamps including Wolgan East swamp (Aurecon 2009, Goldney et al 2010, Enforceable undertaking 2011) and loss of groundwater at Kangaroo Creek lower swamp (Centennial Coal 2009, DECCW 2010b).

Understanding the potential impacts of threats to these swamp ecosystems requires a sound understanding of their developmental processes. Swamp hydrology is the result of interactions between groundwater inputs associated with hydrogeology, and climate, catchment size, geomorphology, overland flows and stream inputs. Climate has a direct influence on the hydrological balance through the interaction between groundwater and the balance between precipitation and evapotranspiration. Evapotranspiration is influenced by other climatic variables such as temperature and wind, and site attributes such as aspect and vegetation (Holland *et al.* 1992a; Holland *et al.* 1992b). The total water balance may be simply expressed as: precipitation = infiltration + run-off + evapo-transpiration. An excess of precipitation over evaporation (positive water balance) is a fundamental requirement for the development of the upland mires (Coastal Heath Swamps, Montane Bogs and Fens) of the study area, and more broadly within the region (e.g. Young 1986a). Groundwater is the result of infiltration and subsequent percolation through permeable (porous or fractured) substrates, with variable residence (storage) times between initial infiltration and any expression at discharge sites. Permeability is a function of porosity and may reflect chemical solution processes, or fracture-controlled or secondary permeability related to joints and bedding planes, fault zones and igneous dykes (McKibben & Smith 2000).

Hydrology and water balance (evapo-transpiration compared to precipitation and other hydrological inputs) are the critical factors in determining the development of peatlands or organic-rich wetland soils; the peaty substrate and its dependence on high moisture levels is a key characteristic of NPSS and THPSSS. A basic requirement for peat formation is that plant biomass production (carbon production) exceeds decomposition (ecosystem respiration or carbon output). Consistently high water tables generally provide the necessary conditions for peat accumulation, particularly in cooler boreal and temperate climatic regions (Gore 1983; Moore 1989, 2002; Moore & Bellamy 1974). Conditions of seasonal drying or widely fluctuating water tables, and/or negative water balance as a result of relatively high evapo-transpiration compared to precipitation, are not conducive to accumulation of peat.

Within the Blue Mountains, peat swamps are characterised by considerable heterogeneity in the distribution, composition and depth of peat or organic-rich soils, within and among swamps (e.g. NPSS, see King 1993). This heterogeneity is often strongly correlated to the spatio-temporal heterogeneity in hydrology within swamp patches, and the distribution of suitable habitat for groundwater dependent species. Particular features of NPSS are the often extensive areas of permanently waterlogged peat.

In this paper we focus on exploring the dependence of the swamps and their taxa on an association with continuing high groundwater levels. In a joint project, with separate author expertise in vegetation (DHB) and mire-dwelling fauna (IRCB), we examined vegetation patterns across and within a range of Newnes Plateau swamps, and by drawing together the occurrences and ecology of threatened biota, assess the crucial importance of water regimes in the composition, structure and function of the listed NPSS community. Given the wide range of threats impacting on these swamps, and in particular those impacts that have potential to change, and in particular reduce water table levels in the swamps, these biodiversity conservation issues need to be faced before actions that potentially result in irreversible damage are set in motion.

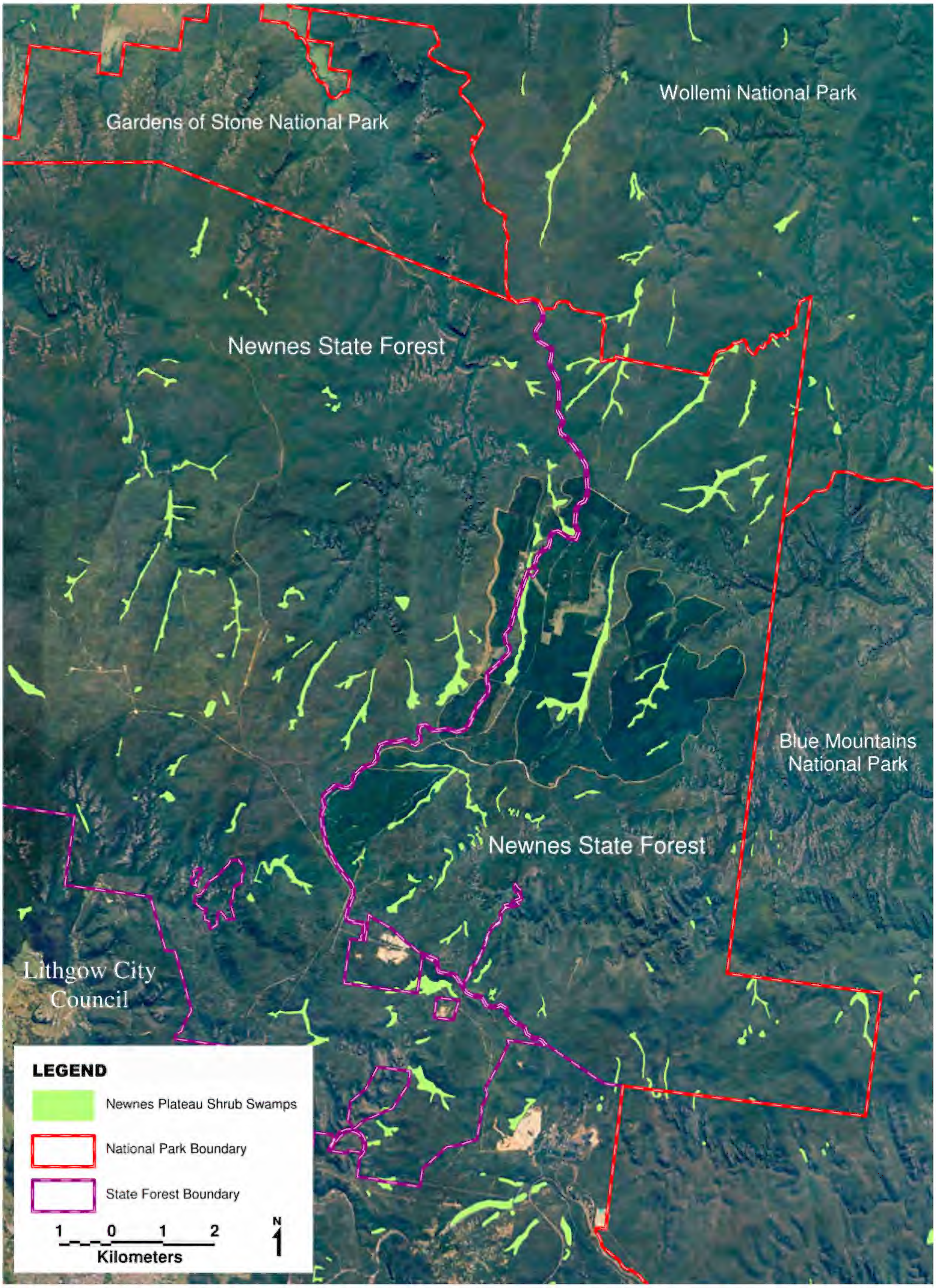


**Fig. 1.** General distribution of Newnes Plateau Shrub Swamps centred on Newnes Pine Plantation showing clusters of swamps **a)** in upper Carne Creek catchment to the west (Left side) of the Pine Plantation and upper Wolgan River (further west); **b)** to the northeast flowing to Rocky Creek and the Wolgan River; **c)** within the Pine Plantation and southeast flowing to Bungleboori Creek and the Wollangambe River **d)** to the far south around Clarence flowing to Dargans Creek; and **e)** southwest flowing to Marrangaroo Creek and to the south flowing to Farmers Creeks. To the far west is Kangaroo Creek, flowing to the Coxs River. Swamp areas are overestimated for easier identification. The double-dotted north-south line within the Pine Plantation indicates the Glow-worm Tunnel Road..

## Study Site

### *Location*

The Newnes Plateau (lat 33° 23' S; long 150° 13'E) is a high elevation sandstone plateau (1000–1180 m elevation) in the western Blue Mountains north of Lithgow. It is mostly under State Forest tenure, with some centrally located exotic pine plantations (*Pinus radiata*), as well as quarries, coal-mines, small rural holdings and a timber mill, surrounded by extensive natural forest, woodland, heath and shrub swamp vegetation. Figure 1 provides an overview of the swamps on the Newnes Plateau. There are few historical names for particular swamps; Browns Swamp at Clarence, and Murrays Swamp used by Deane in 1910 (Australian Railway Historical Society 1979) being exceptions. We have used creek names (where mapped), and the more recent names used in current coal mine company reports (e.g. Springvale Coal 2005, 2008), where applicable. Only one new name has been coined, Broad Swamp, the site of our 1985 and more recent studies. (For names and grid references see Table 4.)

### *Climate*

Rainfall on the Newnes Plateau is relatively high, usually between 880 and 1080 mm p.a. (DEC 2006) with a long-term mean of 1177 mm p.a. (Newnes State Forest Prison Farm records 1939–1998, elevation 1040m). Rainfall is highest in the summer months (Jan– March), but otherwise about 70–75 % of the monthly summer rain falls in other months of the year. Lithgow records are from a lower elevation but show a similar seasonal trend. The Newnes records (1939–1998) pick up the end of the long-term drought (1939–1948) followed by a mild period, but with increasing dryness from 1990 to 1998. Since 1998 drought conditions continued into the mid to late 2000s, followed by higher rainfall in 2011–2012.

Recent work on the geomorphology of the area indicates that during the Last Glacial Maximum (LGM) c. 20 000 years bp, the climate was much drier and the Plateau vegetation was likely to have been treeless (Hesse *et al*. 2003, Wilkinson *et al*. 2005, Wilkinson & Humphreys 2006). With warming climates, swamps began development about 12–14 000 years ago and have been a feature of the vegetation of the Plateau for at least the last 12 000 years (Chalson & Martin 2009).

### *Newnes Plateau Shrub Swamps*

At up to nearly 1200 m, the Newnes Plateau is the highest sandstone area in central southeast Australia, and occupying upland valleys in the headwaters of streams on the Newnes Plateau, at 900–1130 m elevation, and with most above 1000 m are the Newnes Plateau Shrub Swamps, a series of generally narrow elongate low-slope peat swamps. The swamps occasionally occur as hanging swamps on steeper slopes where groundwater seepage occurs as discharge (springs) from rock fracture aquifers or where groundwater is forced to flow laterally to the surface by relatively impermeable strata (aquicludes or aquitards). Swamps develop where the watertable is emergent, and may be associated with perched or extensive unconfined aquifers, or potentially as effluent discharge from confined aquifers (Marshall 2005). Swamps of low gradient valley floors are essentially sediment deposition zones, and have developed in response to impeded drainage and the accumulation of organic-rich sediment and dense hydrophilic graminoid vegetation (e.g. Cyperaceae, Juncaceae, Restionaceae, Xyridaceae, Poaceae). This vegetation further retards surface flow and increases sediment deposition. This process may enhance the development of a perched water table due to its increasing water-holding capacity and slow rates of horizontal seepage. With increasing waterlogging, rates of organic decomposition decrease under more anaerobic conditions leading to the accumulation of peat or at least more organic rich swamp substrates (Keith *et al.* 2006; Young 1986a). Hydrological inputs to these valley floor swamps may include precipitation, overland flows, stream inputs and groundwater inputs where the unconfined (or confined) aquifer emerges within the valley floor. Swamp hydrology is thus a complex interaction between groundwater and climate variables, notably precipitation and temperature, in combination with geomorphic attributes or topographic setting, and permeability of the underlying strata.

The Blue Mountains sandstone aquifer is a complex and poorly understood groundwater-system (DLWC 1999a, b, c). It supports a wide variety of groundwater dependent ecosystems susceptible to changes in groundwater quality and quantity (DLWC 1999c; McKibben & Smith 2000; NSW Government 2002). The best documented of these systems within the study area are those associated with the Narrabeen Group sandstones overlying the Permian Coal Measures in the central-western part of the study area, particularly under the Newnes Plateau and adjoining areas to the west. Bish (1999) reported that both the Illawarra Coal Measures and Narrabeen Group were characterised by fractures that control groundwater flow, and that the regional groundwater system in the Coxs River Catchment included perched, unconfined and confined aquifers. More recent hydrogeological investigations on the western side of the Newnes Plateau (CSIRO 2004) indicated that the study area is characterised by an unconfined aquifer (AQ5) and two confined aquifers (AQ4, AQ3) in Narrabeen Group strata overlying an extensive layer of relatively impervious Mt York Claystone though the Mt York Claystone does not appear to outcrop within the main altitudinal range of NPSS. This, in turn, overlies two additional confined aquifers (AQ2, AQ1) associated with clay-rich or otherwise low permeability strata in the Illawarra Coal Measures (Centennial Coal 2005; CSIRO 2004; Springvale Coal 2005). The extensive unconfined aquifer (AQ5) of this area was reported to be generally responsible for groundwater inputs to the swamps of the Newnes Plateau, although a perched water table has been inferred to occur in association with the small Junction Swamp (Centennial Angus Place 2006; Springvale Coal 2005).

Piezometer data across a number of NPSS and associated headwater streams are gathered for environmental monitoring of the extensive underground coalmines under the area including Angus Place (Centennial Angus Place 2006; Centennial Coal 2005), Springvale (Springvale Coal 2005, 2008), Clarence (Campbell 2007) and Baal Bone Collieries. While descriptions of NPSS have implicitly recognised the importance of moisture levels for the swamp species, there has been a recognition that hydrological regimes vary among individual swamps. Monitoring of some swamps in the western part of the Newnes Plateau (e.g. West Wolgan Swamp) has suggested that these swamps are drier than those on the east and have a greater reliance on precipitation than groundwater inputs compared to other swamps further east on the Plateau. There is also more frequent surface drying (Centennial Angus Place 2006) which is reflected in the relatively low organic content of those swamp soils (see also Benson & Keith 1990). In contrast, those on the eastern side are generally accepted as being associated with an unconfined aquifer that provides permanent groundwater inputs, and consequently are more highly groundwater dependent ecosystems (GDEs). Piezometer data indicate that the water table of Newnes Plateau swamp systems demonstrates a rapid, relatively short-term response to rainfall events (Goldney *et al.* 2010) and gradual longer-term trends in water table drawdown associated with drought cycles (M Krogh pers. comm.). Systems likely to cope with intermittent waterlogging are likely to be more resilient to change than those with permanent moisture requirements. Conversely, the NPSS with permanently high water tables are more highly dependent on groundwater inputs than precipitation, and less likely to be resilient to long-term hydrological changes. These latter swamps are likely to be the habitats of the identified threatened species.

### *Vegetation*

Newnes Plateau Shrub Swamps are characterised by wet heath shrub species including *Baeckea linifolia, Boronia deanei* subsp. *deanei, Callistemon pityoides, Grevillea acanthifolia* subsp. *acanthifolia*, and *Epacris* and *Leptospermum* species (see NSW Scientific Committee 2005). Species abundance varies along gradients of moisture and soil type (Benson & Keith 1990; DEC 2006). Where there is permanent moisture and a relatively high water table, tussock sedgeland with *Gymnoschoenus sphaerocephalus, Xyris ustulata, Empodisma minus*, *Gleichenia dicarpa*, and *Leptospermum* spp.) predominate; while drier sites include herbs such as *Viola* sp., *Xyris gracilis* and *Xanthosia dissecta.* Margins of the swamps with surrounding woodlands are sharp and there is little intermixing of species.

With decreasing altitude, NPSS grade into Blue Mountains Sedge Swamps (BMSS) communities (DEC 2006), the transition occurring between Bell and Clarence at approximately 850–950 m elevation. Other features that distinguish NPSS from BMSS include the presence of high elevation shrub species in the former (such as *Hakea microcarpa*, *Dillwynia stipulifera* and *Boronia deanei)*, and its occurrence on long low slope valley terrain, compared with the often steep seepage slopes and perched headwater valleys (though sometimes including low slope valley swamps) that typifies BMSS habitats at lower elevations in the Blue Mountains. Blue Mountains Sedge Swamps generally have less cover of shrubs and a greater cover of sedges (particularly *Gymnoschoenus sphaerocephalus*) than NPSS. For example, at Cold Foot Swamp on the Mt Hay road, Holland *et al.*(1992a) recorded an extensive area of permanent swamp dominated by *Gymnoschoenus* with only a fringe of shrubs; though many BMSS are also dominated by dense heath or scrub. Interestingly, the wettest BMSS valley floor swamps may have deeper peats than NPSS.

### *Key Swamp dependent biota*

While most of the swamp-dwelling species are swamp-dependent in that they are generally restricted to moist habitats, many of these species are relatively common and widespread across the range of the THPSS with some common beyond. However, NPSS are also habitat for some taxa that are rare or restricted within the ambit of the THPSS and have been listed individually as threatened flora or fauna. In our view the relationship of swamp hydrology to these key species is a major conservation science issue for these swamps.

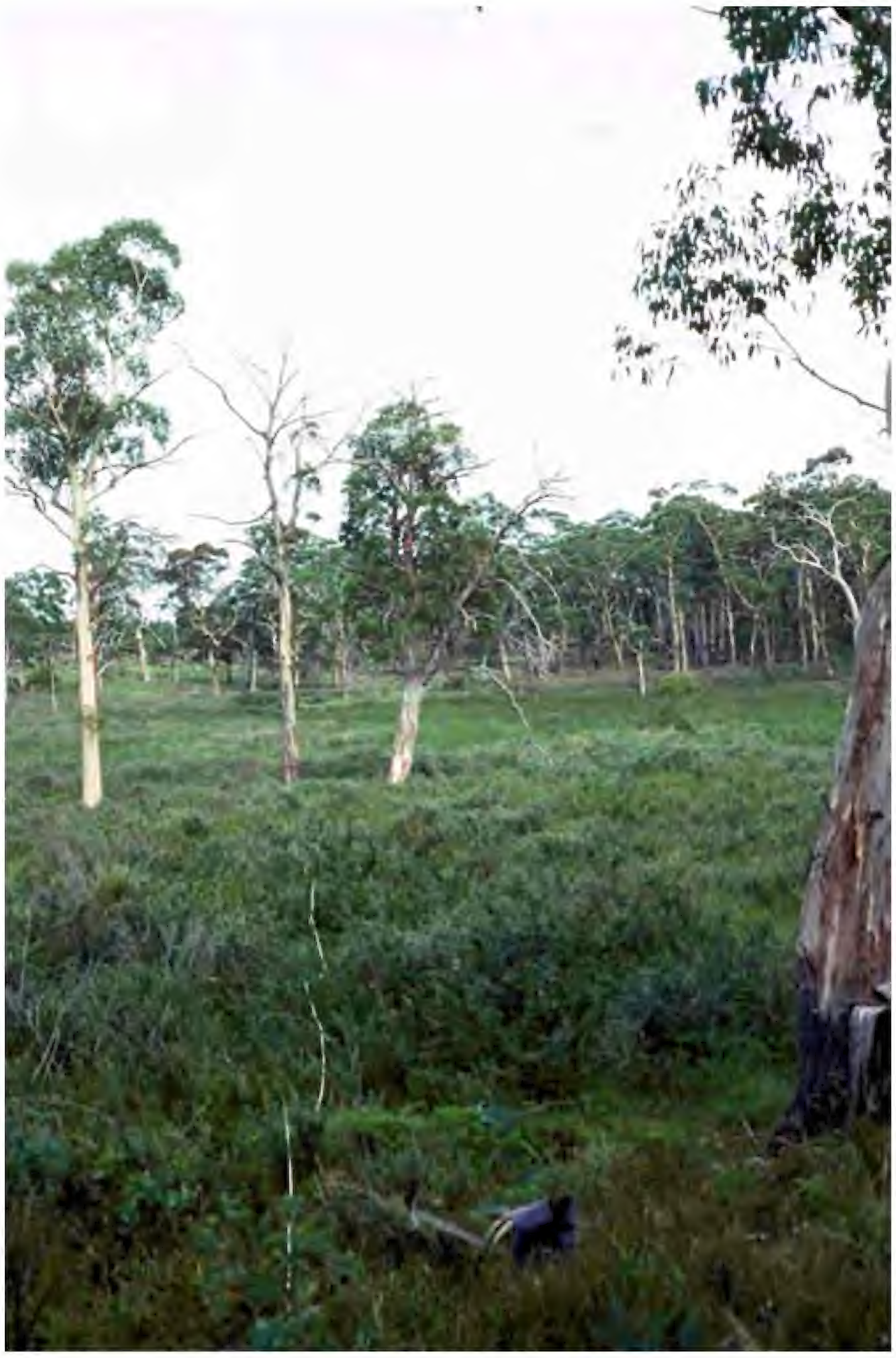
Below are notes on key threatened species studied here, and two swamp dependent species, not listed as threatened, but either rare and regionally restricted to NPSS (*Dillwynia*), or that interact with the ecology of the threatened species and may fulfil important ecological and functional roles within these groundwater dependent ecosystems (*Euastacus*). Some additional species are included in the later discussion of rare species on the high elevation plateau (Table 6).

### *Boronia deanei* subsp. *deanei*

Deane's Boronia, *Boronia deanei* subsp. *deanei* (Rutaceae) is a shrub species generally about 1m high, occurring in localised patches that are most distinctive as patches of pink flowers in spring, particularly in the larger NPSS in the Carne Creek catchment and north of Clarence. A separate and disjunct group of populations occur in various swamps on the Boyd Plateau on granite geology (Kodela *et al.* 1996), about 70 km south of Newnes Plateau. *Boronia deanei* subsp. *deanei* is listed as Vulnerable under the NSW TSC Act. (The related subspecies, *Boronia deanei* subsp. *acutifolia,* also listed as Vulnerable, occurs in two disjunct areas on the Southern Tablelands, Fitzroy Falls/Budderoo, and Nalbaugh National Park near the Victorian border).

### *Petalura gigantea*

The giant dragonfly, *Petalura gigantea* (Odonata: Petaluridae) is a very large dragonfly and equally the fifth largest in Australia with a wingspan up to at least 13 cm. Like most petalurid dragonflies, *Petalura gigantea* are characterised by a fossorial (burrowing) larval lifestyle (Baird 2012; Tillyard 1911) that is unique in the Odonata (Corbet 2004). A long larval stage of at least five years has been documented in other fossorial petalurids internationally, and studies to date suggest a larval stage of at least six years, and possibly more than 10 in *Petalura gigantea* (for review,



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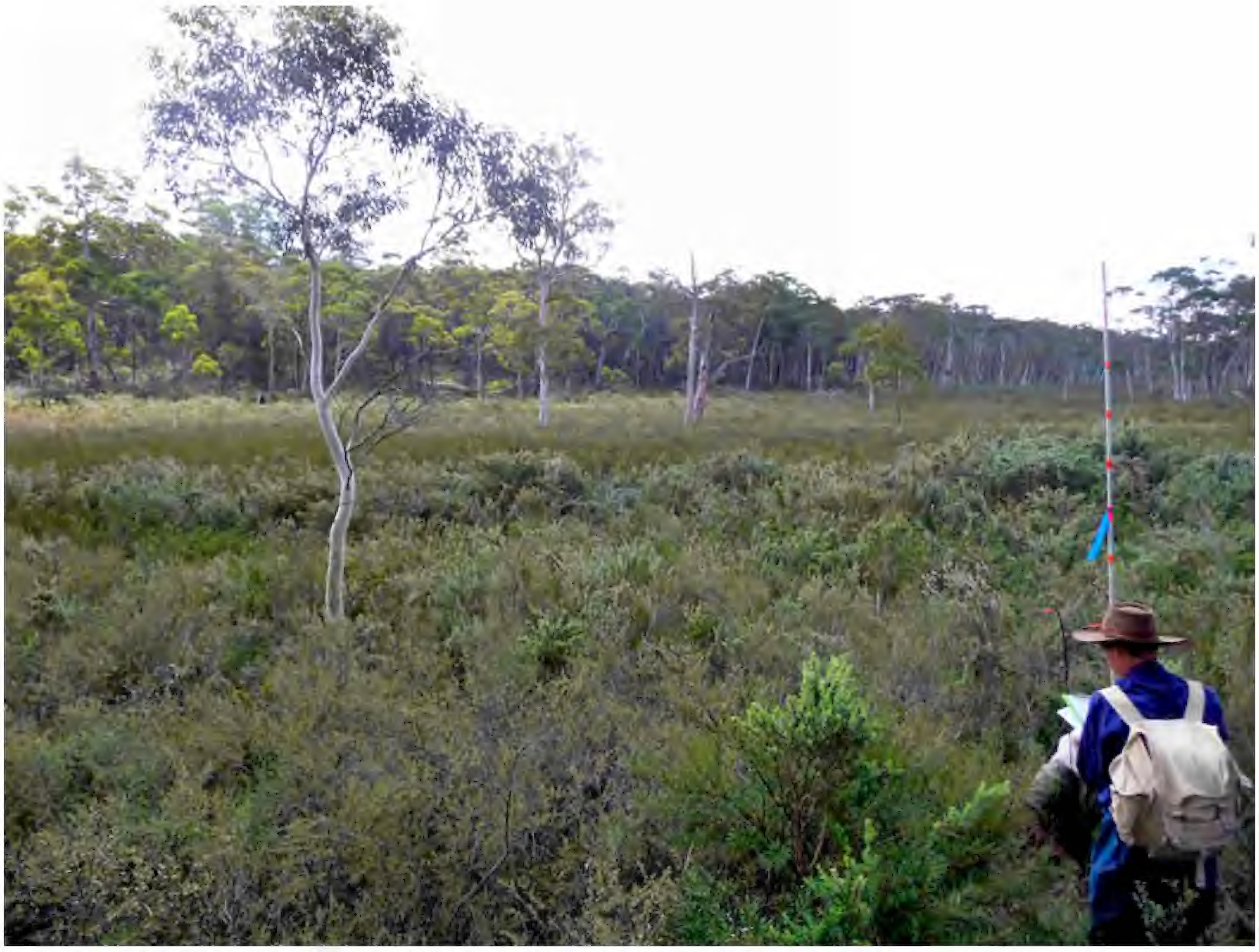

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**Fig. 2**. Photos of Broad Swamp in **a)** 1985, view looking east showing trees along shallow interfluve ridge, and **b)** 2012, looking northwest from opposite side, showing similarly placed trees.(photos DHB, M. Krogh) see Baird 2012). The species has a late spring to summer flying and breeding season, with imagos persisting for one season. *Petalura gigantea* has been recorded from swamps, bogs and seepages along the coast and ranges of NSW, with a patchy distribution extending from near the Victorian border to the far Northern Tablelands, and from near sea level to 1240 m altitude (Baird 2012; Theischinger & Endersby 2009; Trueman 2000). The species appears to be restricted to the following freshwater wetland vegetation classes of Keith (2004): Coastal Heath Swamps, Montane Bogs and Fens, and possibly peripheral to Coastal Freshwater Lagoons. In the latter case, any occurrence may be associated with patches of Coastal Heath Swamp. Within the Blue Mountains region, it has been recorded from a number of swamp or mire types, including NPSS (Baird 2012).

Successful *Petalura gigantea* breeding sites are characterised by a groundwater regime that provides sufficient surface moisture to minimise risk of desiccation of eggs and early larval instars, supports development of organic-rich peatland (mire) soils suitable for larval burrowing, and maintains a water table height that larvae can access within established burrows or adaptively through burrow deepening. For this reason the species is considered to be an obligate groundwater dependent mire dwelling species (Baird 2012).

*Petalura gigantea* is listed as Endangered under the TSC Act 1995, with declining population size, and loss or degradation of wetland habitats in which it occurs, identified as threats to its survival (NSW Scientific Committee 1998). All swamp types where *Petalura gigantea* has been recorded in the Blue Mountains are either specifically identified within descriptions of Commonwealth (EPBC Act 1999) or NSW (TSC Act 1995) EECs or could be considered covered by one of these listings.

### *Eulamprus leuraensis*

The Blue Mountains water skink, *Eulamprus leuraensis* (Scincidae) is endemic to mid to upper elevation BMSS and to NPSS (Dubey & Shine 2010; LeBreton 1996; NPWS 2001). The species is viviparous and grows to 64 (–72) cm (SV) long (Swan *et al.* 2004). It is known to use burrows of the crayfish *Euastacus australasiensis* as both fire and predation refugia (I.R.C. Baird pers. obs.). In addition to identified threats (urban development, pollution, sedimentation, alteration to hydrological regimes, weed invasion, visitor disturbance, cat predation) (NPWS 2001), climate change has been identified as a potential threat to this stenotopic, patchily distributed reptile (Dubey & Shine 2010). A recent genetic study has identified low rates of genetic exchange and high genetic divergence between discrete swamp populations, and recommended that most populations be treated separately as discrete conservation units (Dubey & Shine 2010). The species is listed as Endangered under the TSC Act 1995 and the EPBC Act 1999.

### *Dillwynia stipulifera*

*Dillwynia stipulifera* (Fabaceae) is a small shrub restricted to swamps on the Newnes Plateau with disjunct occurrences on the South Coast in wet heath and mallee in Morton National Park at Corang Peak and south of Sassafras.

### *Euastacus australasiensis*

The burrowing Australian crayfish *Euastacus australasiensis* (Decapoda: Parastacidae) occurs in streams and upland swamps of the Sydney region, including the swamps of the Newnes Plateau (Growns & Marsden 1998; Merrick 1998; Morgan 1997; Buchanan 1980; Young 1980); on current knowledge it is the only indigenous upland swamp dwelling crayfish within the Blue Mountains. *Euastacus* may occur in both valley floor swamps and hanging swamps on valley sides and may be locally abundant in individual swamps Although not listed as threatened, its burrows have been observed to provide fire and predation refugia for *Eulamprus leuraensis* (IRCB pers obs.). Burrow investigations within Blue Mountains swamp systems have not been undertaken, but investigations of Tasmanian mire dwelling crayfish (*Parastacoides* spp.) have revealed complex burrow structures, groundwater dependence and unique functional roles (e.g. Growns & Richardson 1988; Richardson & Swain 1980, 1991).

## Methods

### *Swamp selection and measurement*

The Newnes Plateau Shrub Swamps occur scattered over an area of c. 440 km$^2$. Henson (2010) has included 75 of these swamps in an aerial survey of the Newnes Plateau, but this is far from being a comprehensive list as it excludes many other, particularly smaller swamps. Henson's list also includes swamps of Ben Bullen State Forest and Angus Place to the west of the Plateau, which have been mapped as Coxs River Swamps (see Benson & Keith 1990). The general distribution of NPSS (Figure 1) is centred on Newnes Pine Plantation and consists of clusters of swamps: a) in upper Carne Creek catchment to the west of the Pine Plantation (including study sites underlined– Carne West, Gang Gang West, Carne Central and Broad Swamps) and upper Wolgan River (further west) (West Wolgan, East Wolgan Swamps); b) to the northeast flowing to Rocky Creek and the lower Wolgan River (Deanes Creek Swamp); c) within the Pine Plantation and southeast flowing to Bungleboori Creek and Wollangambe River (Pine Swamp) d) to the far south around Clarence flowing to Dargans Creek; and e) southwest flowing to Marrangaroo Creek (Marrangaroo Swamp) or Farmers Creek and f) to the northwest (Kangaroo Creek Upper and Kangaroo Creek Lower Swamps) flowing to the Coxs River.

In the current study, transects were recorded from 10 swamps, while many others have been visited by us during periods of fieldwork. The concentration of these, including some of the largest ones, in the upper catchment of Carne Creek is a major feature of their distribution, and a series of swamps here were selected for examination. Additional swamps at higher and lower elevations were also sampled. Swamp margins show relatively clearly in air-photo overlays and the physiographic attributes of the study site swamps – length, breadth, elevation, slope – were compiled from 1:25 000 topographic maps.

### *Vegetation spatial patterns*

In February 1985 a series of vegetation transects were recorded in a large swamp (Broad swamp) (lat 33° 22' 44.9", long 150° 13' 41.74", elevation 1046 m) in the Carne Creek headwaters (Figure 2). This swamp included an extensive population of *Boronia deanei* and other characteristic swamp plant species; at the time (1985), the proposed above-ground mining and washery infrastructure of the planned Birds Rock colliery directly threatened this swamp and others nearby.

Analyses of the 1985 data showed species clusters related to soil moisture but were difficult to interpret spatially as surface and sub-surface topography had not been measured. To gain a better understanding of vegetation in relation to surface water and peat depth patterns, additional transects across a representative selection of the main NPSS were recorded in February 2012. Swamps selected ranged from highest elevation westerly sites to lower elevation ones in the northeast, and included a major component of the mid elevation swamps known to be habitat for the particular threatened species listed above. Plant species occurrence was recorded in a pair of 0.5 x 0.5 m quadrats at 5 m intervals along a transect across each swamp from edge to edge, generally at its widest point, and generally transverse to the main drainage line. Transects ranged in length from 35 m to 130 m. At each sampling point sediment/peat depth was measured with a probe, and the relative height of the soil surface measured using a pocket level and measuring staff. This enabled construction of swamp profiles showing soil depth in relation to soil surface.

Our use here of transverse transects with 10 to 30 subplots to characterise swamp vegetation is the first time (apart from 1985) that sampling has taken into account the variation in vegetation that occurs across these swamps, which may be 50–100 m across; previous studies (e.g. DEC 2006) and monitoring has usually relied on only one or two 20 x 20 m quadrats per swamp.

The vegetation data were examined firstly for any clustering of swamps across the Plateau, and then for patterns within individual swamps, mainly in the larger Carne Creek/Clarence/eastern swamps (Figure 1). To provide an indication of any substantial change over time, 1985 and 2012 patterns within Broad Swamp were compared. Analyses of the vegetation data used multivariate packages in Primer v6 (Clarke and Gorley 2006)[1], with presence/absence data and Bray-Curtis similarity measure to construct MDS ordinations and dendrograms; and PATN (Belbin 2004) using the Bray Curtis similarity measure with Flexible UPGMA (for sites); and Two-step with Flexible UPGMA dendrograms and Two-way tables (for species).

### *Substrate depth and waterlogging*

Substrate depth was determined using a 1.8 m x 8 mm diameter steel rod probe, measuring at each vegetation plot along each swamp transect. The probe was either pushed until it reached bedrock, until it was not possible to easily push further, or until it reached 1.8 m depth (measurements were taken by the same observer to maintain consistency). The rationale was to record the depth of more organic-rich swamp sediment (up to 1.8 m) that could be differentiated from denser mineral substrates due to its higher penetrability. Very few records were >1.8 m deep.

### *Groundwater dependent biota*

The transects included recording occurrence of the identified groundwater dependent biota *Boronia deanei* and *Dillwynia stipulifera*, and observations of any *Eulamprus leuraensis*. To relate potential *Petalura gigantea* breeding (oviposition and larval burrow) habitat to vegetation and substrate attributes, a *Petalura* index was recorded by *Petalura gigantea* expert IRCB (0= not suitable habitat, 1= possible habitat, 2= highly likely habitat). At the same time, surface moisture depth was measured. Based on the experience of IRCB, sites with recorded and potential habitat may be treated similarly in the context of this study, for comparison of habitat attributes.

The occurrences of the swamp-dependent biota were tabulated; including all recorded and potential *Petalura gigantea* sites in Newnes Plateau Shrub Swamps (IRCB records, NSW Wildlife Atlas and this study), and records of *Eulamprus leuraensis* (NSW Wildlife Atlas, IRCB records) and *Boronia deanei* on the Newnes Plateau (National Herbarium of NSW and DHB records).

Additional observations have come from other sources, including vegetation notes from various swamps by DHB (during vegetation mapping and survey 1975–85, 2007–11); studies of *Petalura* and its habitat (between 2003–11 by IRCB as part of his doctoral research); and habitat and behavioural observations of *Eulamprus leuraensis* and *Euastacus australasiensis* (IRCB pers. obs.). For example, Baird (2012) investigated 40 *Petalura gigantea* burrows across four swamp types in the Blue Mountains, and documented burrow morphology and their relationship with groundwater depth within burrows. In addition, observations of the location of hundreds of burrow openings and oviposition locations across more than six years of fieldwork, and the characteristics (organic content and waterlogging determined qualitatively) and depth of the substrate at burrow locations (see Baird 2012) have also informed the analysis.

## Results

### *Physiographic features of the swamps*

Typically the NPSS have a narrow elongate shape, though larger swamps have broader lobes associated with side drainage lines. Most swamps are relatively long; those studied ranging from 2 km for Pine Swamp down to 700 m for West Wolgan (Table 1). Longitudinal swamp gradients are relatively gentle with total vertical elevational drops for individual swamps over their lengths ranging from 60 m/

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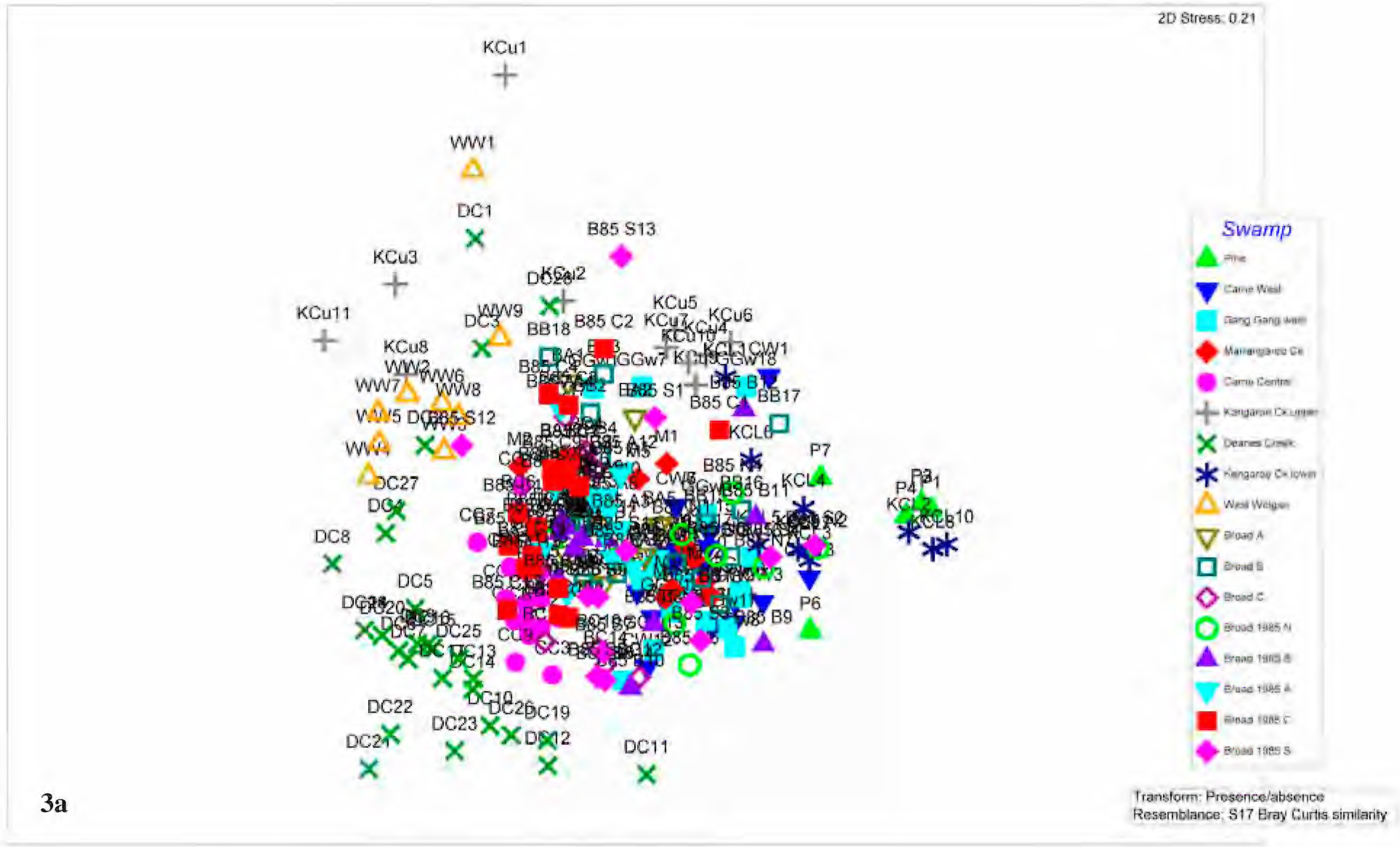
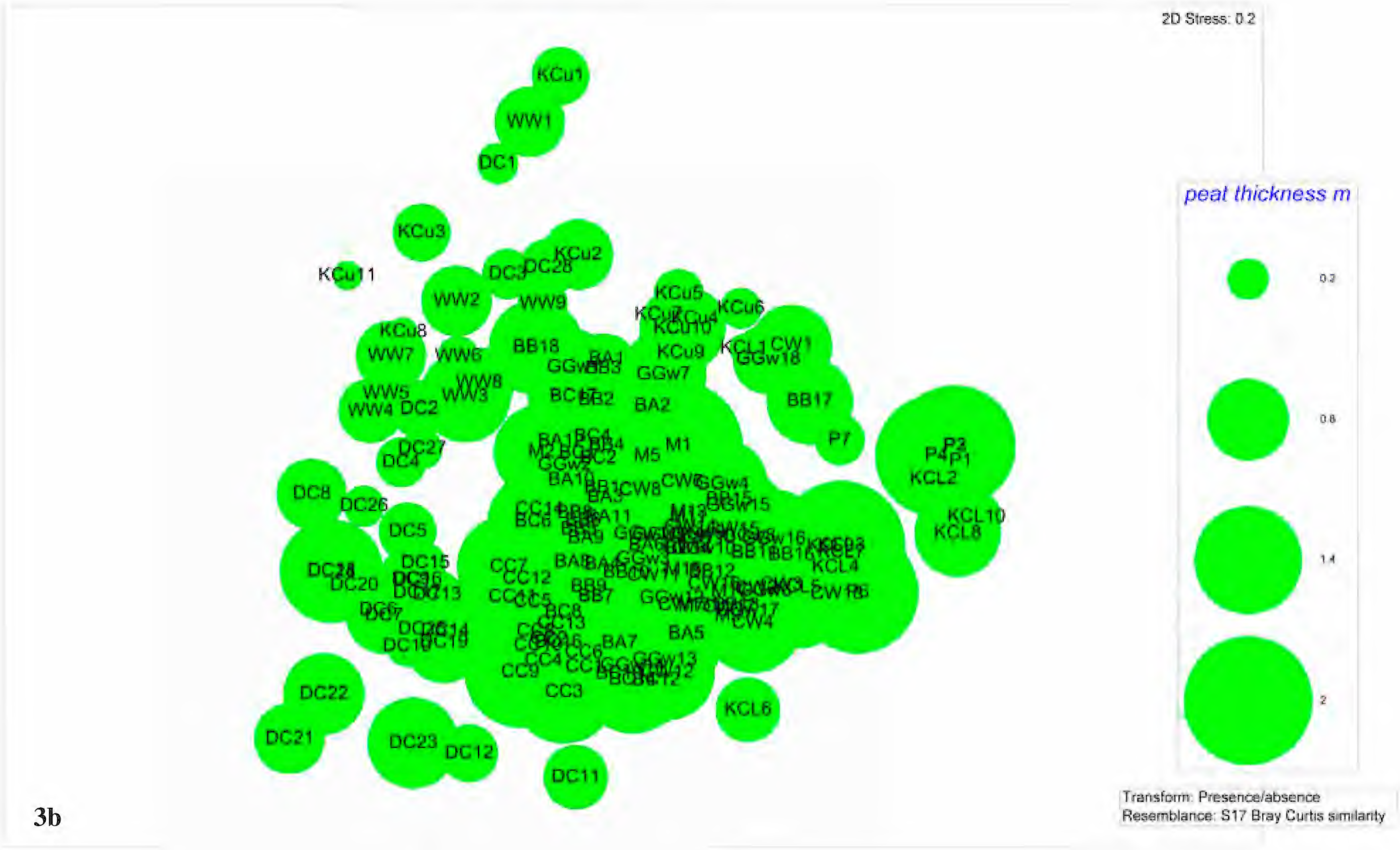
[1] Clare, K.R. and Gorley, R.N. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E: Plymouth.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Broad (BS) | 1080 | 1040 | 1500 | 27 | 130 | 20 | 1.4 | | 40 | 150(AB);<br>85(C) |
| Carne Central (CC) | 1090 | 1060 | 750 | 40 | 100 | 5 | 1.6 | 1.21 | 14 | 65 |
| Gang Gang west (GGw) | 1100 | 1050 | 1500 | 33 | 100 | 5 | 1.2 | 0.82 | 18 | 85 |
| Carne west (CW) | 1100 | 1060 | 1700 | 24 | 80 | 10 | >1.8 | 0.96 | 18 | 85 |
| Marrangaroo Creek (M) | 1100 | 1040 | 1000 | 60 | 80 | 5 | >1.8 | 1.13 | 9 | 80 |
| Kangaroo Creek lower (KCL) | | | | | | 5 | >1.8 | 0.68 | 10 | 45 |
| Pine (P) | 1120 | 1060 | 2000 | 30 | 80 | 10 | 1.8 | 1.3 | 7 | 30 |

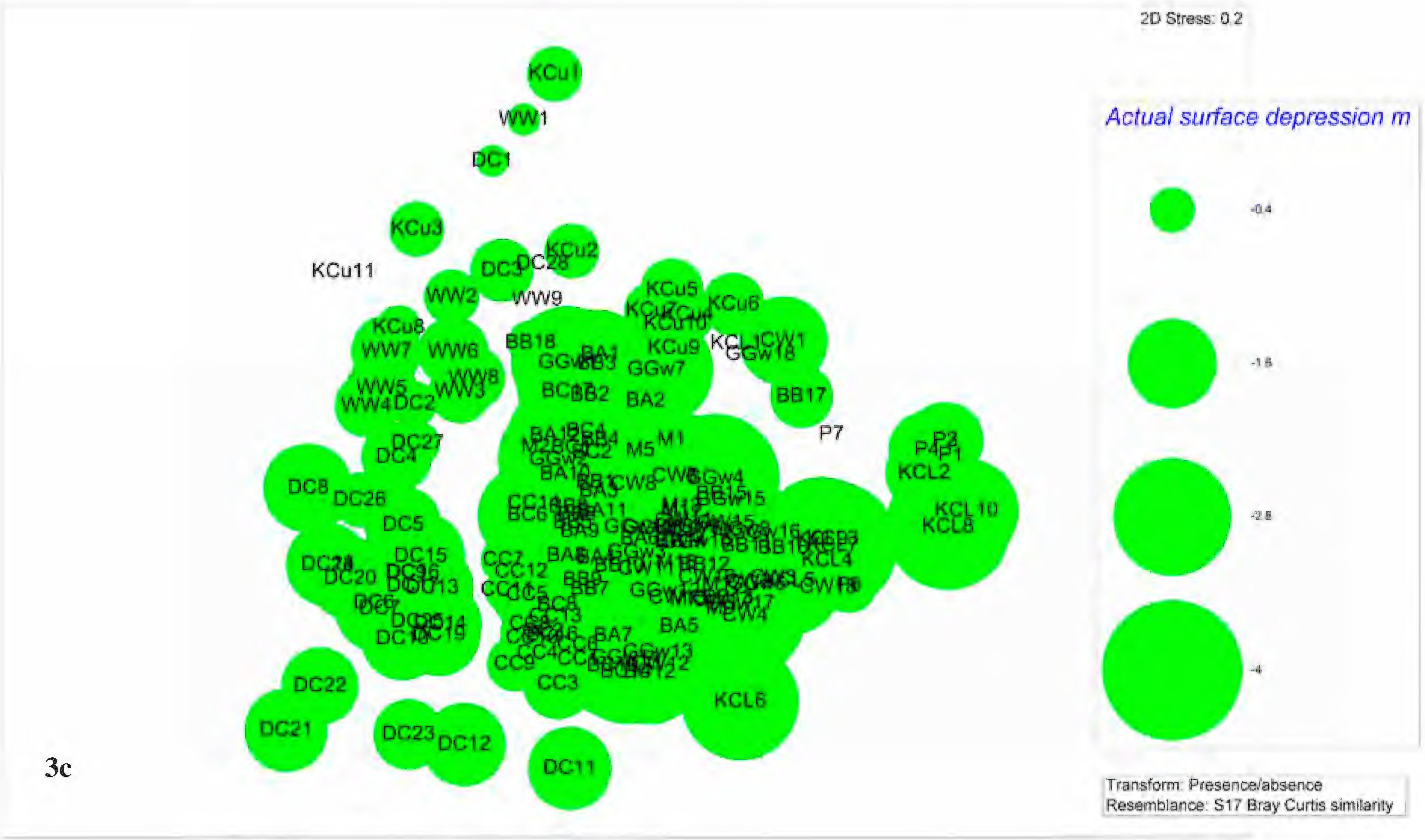


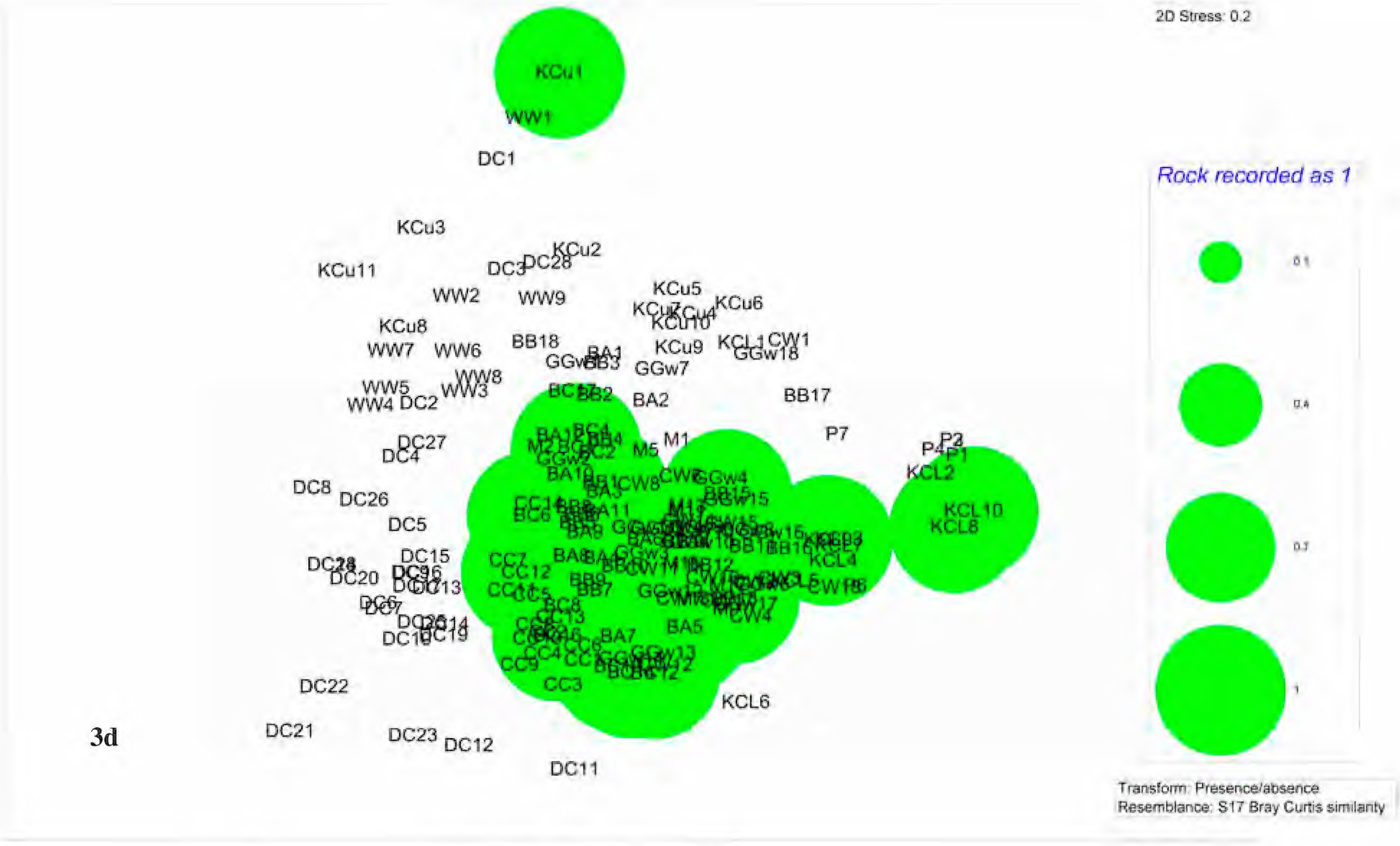
**3a**



**3b**

**Fig. 3 a-g.** Ordination of swamps sites showing **a)** central concentration of wet (Carne/ Clarence/eastern) swamps clustered separately from drier ones, Kangaroo Ck Upper, West Wolgan **(top left)**, and Deanes Ck **(bottom left)**; and swamp sites associated with **b)** greatest peat thickness; **c)** surface depression; **d)** presence of rock below the peat; **e)** surface water; **f)** high *Petalura* index and **g)** *Boronia deanei* occurrence.


2D Stress: 0.2
Actual surface depression m
-0.4
-1.6
-2.8
-4
Transform: Presence/absence
Resemblance: S17 Bray Curtis similarity
3c
KCu1
WW1
DC1
KCu3
KCu2
DC3
DC28
KCu11
WW2
WW9
KCu5
KCu6
KCu8
WW7
WW6
BB18
KCu9
KCL1
CW1
GGw18
GGw7
WW5
WW4
DC2
WW3
WW8
BA2
BB17
P7
DC27
DC4
M5
M1
P2
P4
P1
KCL2
DC8
DC26
KCL10
KCL8
DC5
DC15
CC7
CC12
KCL4
DC20
DC13
BA7
BA5
DC22
CC3
KCL6
DC21
DC23
DC12
DC11


2D Stress: 0.2
Rock recorded as 1
0.1
0.4
0.7
1
Transform: Presence/absence
Resemblance: S17 Bray Curtis similarity
3d
KCu1
WW1
DC1
KCu3
KCu2
DC3
DC28
KCu11
WW2
WW9
KCu5
KCu6
KCu8
WW7
WW6
BB18
KCu9
KCL1
CW1
GGw18
GGw7
WW5
WW4
DC2
WW3
WW8
BA2
BB17
P7
DC27
DC4
M5
M1
P2
P4
P1
KCL2
DC8
DC26
KCL10
KCL8
DC5
DC15
CC7
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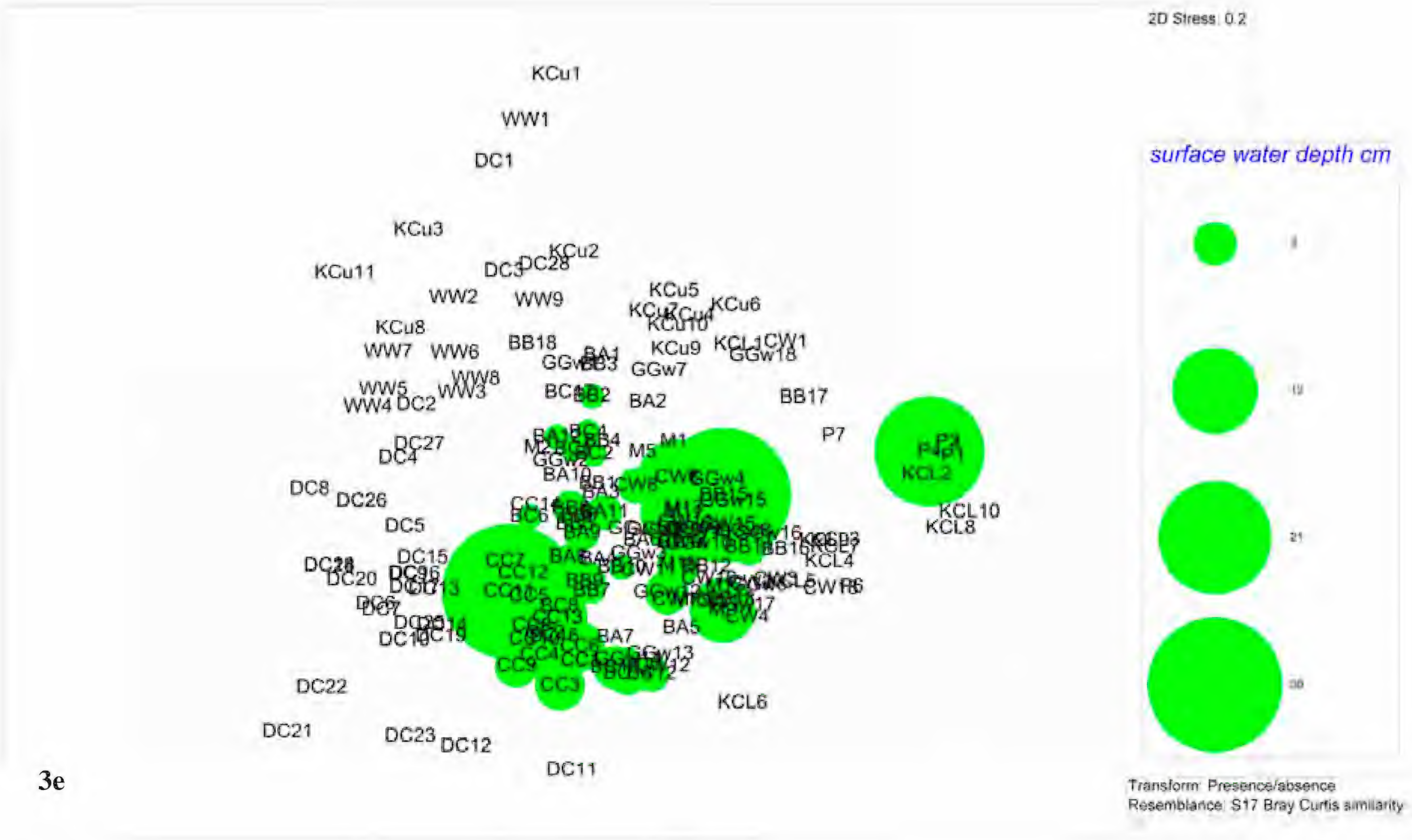
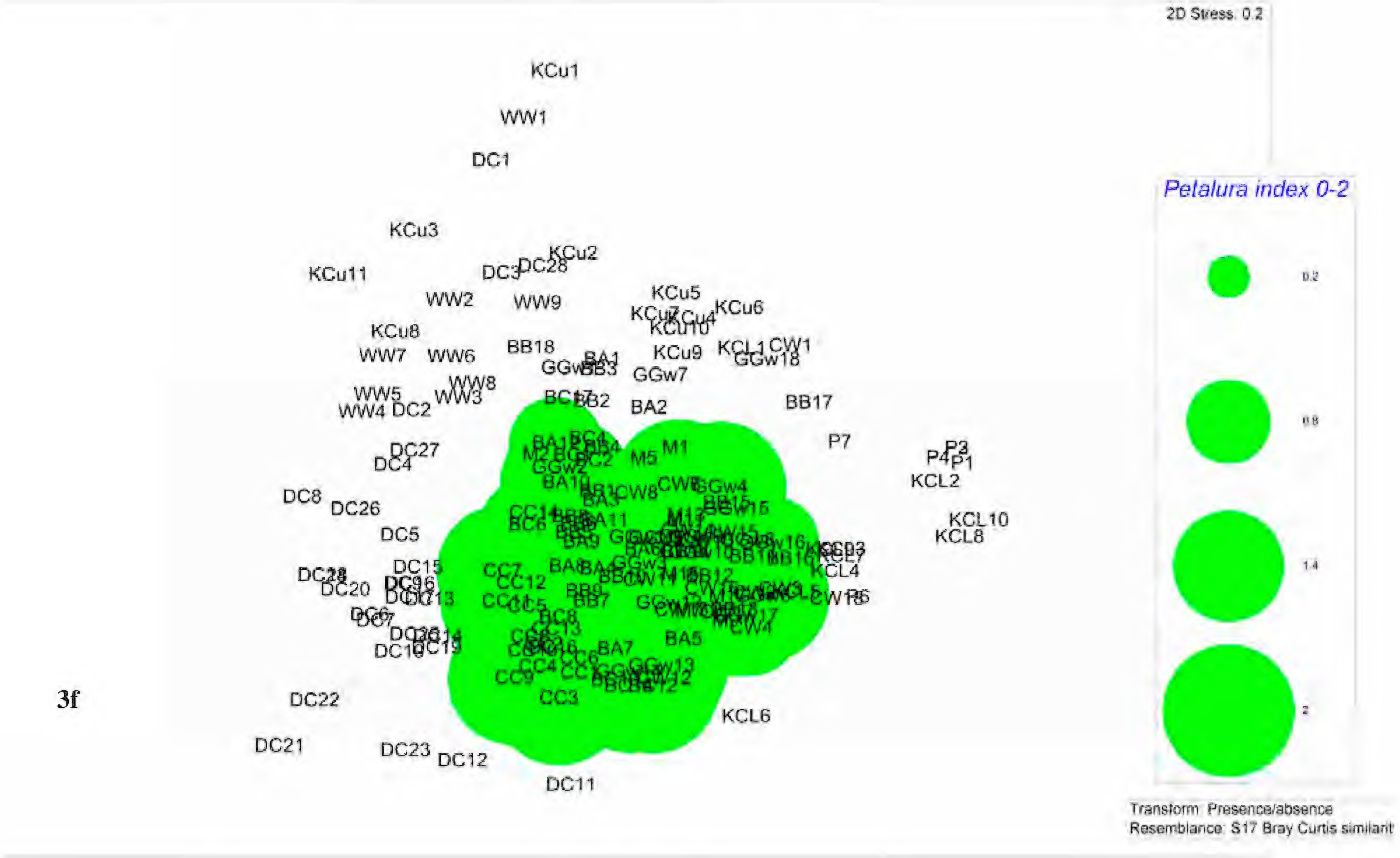
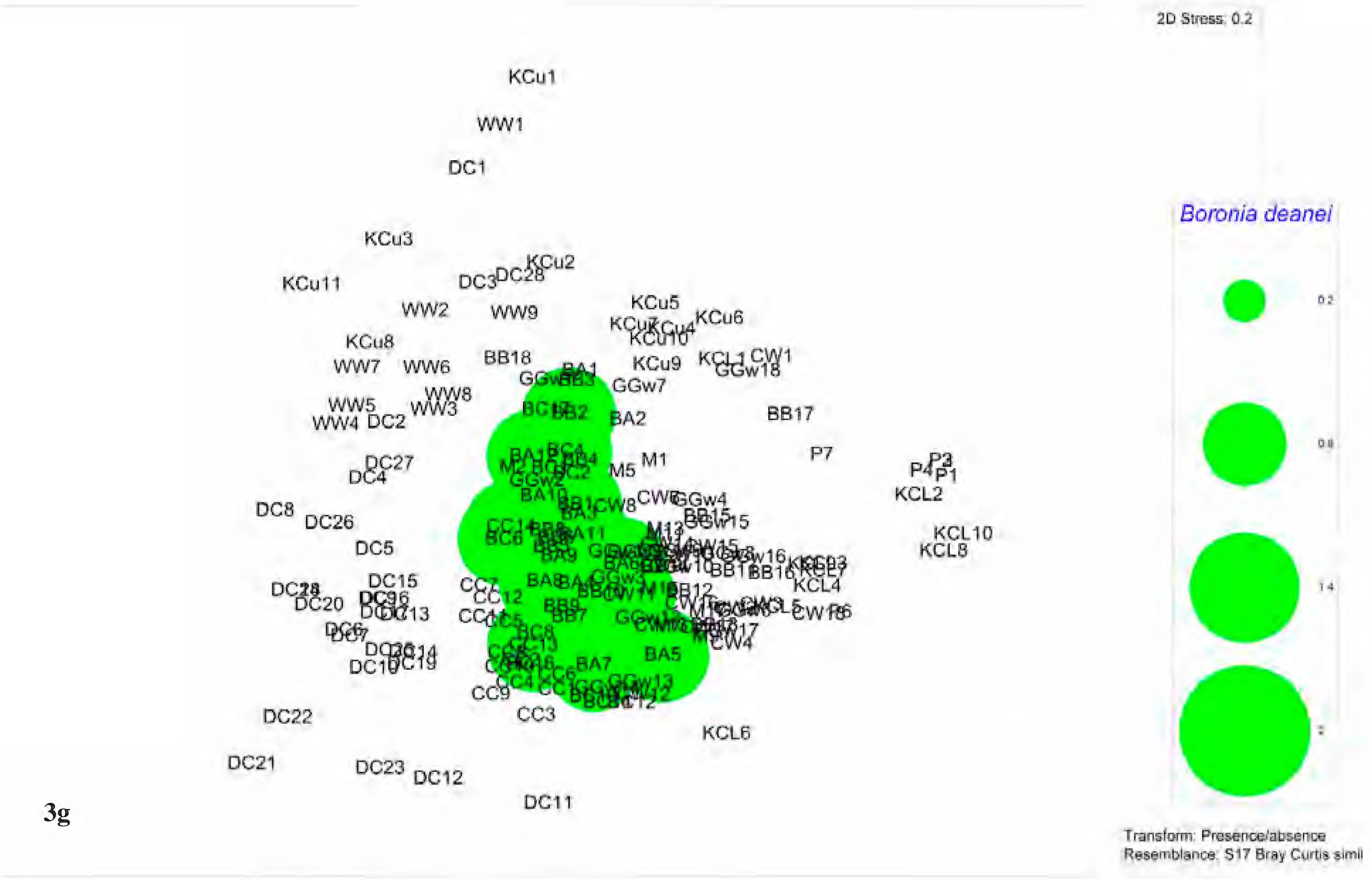
CC3
KCL6
DC21
DC23
DC12
DC11


2D Stress: 0.2
surface water depth cm
3
12
21
30
Transform: Presence/absence
Resemblance: S17 Bray Curtis similarity
KCu1
WW1
DC1
KCu3
KCu2
KCu11
DC3
DC28
WW2
WW9
KCu5
KCu6
KCu8
WW7
WW6
BB18
KCu9
KCL1
CW1
GGw18
GGw7
WW5
WW4
DC2
WW8
WW3
BA2
BB17
P7
P3
P4
P1
KCL2
DC27
DC4
M1
M5
DC8
DC26
DC5
KCL10
KCL8
DC15
DC20
KCL4
CW15
BA5
BA7
GGw13
DC22
CC3
KCL6
DC21
DC23
DC12
DC11

3e


2D Stress: 0.2
Petalura index 0-2
0.2
0.8
1.4
2
Transform: Presence/absence
Resemblance: S17 Bray Curtis similarit
KCu1
WW1
DC1
KCu3
KCu2
KCu11
DC3
DC28
WW2
WW9
KCu5
KCu6
KCu8
WW7
WW6
BB18
KCu9
KCL1
CW1
GGw18
GGw7
WW5
WW4
DC2
WW8
WW3
BA2
BB17
P7
P3
P4
P1
KCL2
DC27
DC4
M1
M5
DC8
DC26
DC5
KCL10
KCL8
DC15
DC20
KCL4
CW15
BA5
BA7
GGw13
DC22
CC3
KCL6
DC21
DC23
DC12
DC11

3f



**3g**

### *Surface and subsurface topography and soil depth*

Cross-section profiles of the swamps show considerable variation in topography at both surface and subsurface levels (Figure 6, Appendix 1), rather than the simplistic picture of the swamps as broadly concave or bowl-shaped as previously assumed, at least by us. Swamp surfaces are generally asymmetrically concave with lowest depression to one side of the centre-line, generally adjacent to the steepest, but not necessarily highest side; one side of the swamp often extends further upslope than the other (e.g. see Figure 6b– Gang Gang West).

Swamp subsurface levels (i.e. bottom of peat deposit) rarely parallel surface levels, particularly in the narrower swamps, but are more complicated, and with stronger asymmetry. A marked feature of many of the subsurface profiles is that they are biconcave, with an asymmetric central ridge (e.g. see Appendix 1 – West Wolgan; Figure 6a – Carne West). The ridges relate to subsurface interfluves between the main and side drainage lines where these run parallel before converging (presumably reflecting the occurrence of pre-swamp drainage lines). At the surface they result in narrow peninsulas of mineral soils or islands of shallower peat over mineral soils. Where the peat is absent or very shallow these interfluves may support woodland and swamp margin species and even occasional eucalypts, despite being located in the middle of the swamp. The relatively shallower peat showed up in the vegetation along the transect AB across Broad Swamp which cut across one of these 'interfluve ridges' (Figure 6d), though in other swamps the total depth of peat may reduce any vegetation effect.

Peat depth depends on the relative shape of the surface and subsurface features. It is closely related to the topography of the underlying valley floor, and is not necessarily apparent from surface vegetation except where shallow as described above. Plots with the deepest peat (mean 1.3 m) were in Kangaroo Creek Lower and Pine, narrow, relatively steep-sided swamps, and associated with *Gleichenia*. Peat depths in the Carne/Clarence/eastern swamps ranged from 0.6 – 1.3 m, but, for the western swamps were substantially less, 0.3–0.6 m.

In addition to depth, soil probes also suggested a complex developmental history for swamp sediments, with considerable variation in substrate characteristics, at and among probe locations within individual swamps. Variation in penetrability and sediment coarseness was able to be determined qualitatively during this exercise, with contrasting layers evident. Fine and coarse sands, clayey material and soft waterlogged peats could all be differentiated during this process as the probe is pushed more deeply. Particularly noticeable were contrasting layers between highly penetrable peat, and dense sands or sandy clays. Probe locations with such contrasting layers were generally located either near swamps edges with adjoining non-swamp habitats upslope, or in association with drainage lines. In both cases, based on the results of the swamp cross-sectional profiling, it may be presumed that these contrasting layers are the result of episodic disturbance events throughout the developmental history of these swamps. These events may result in

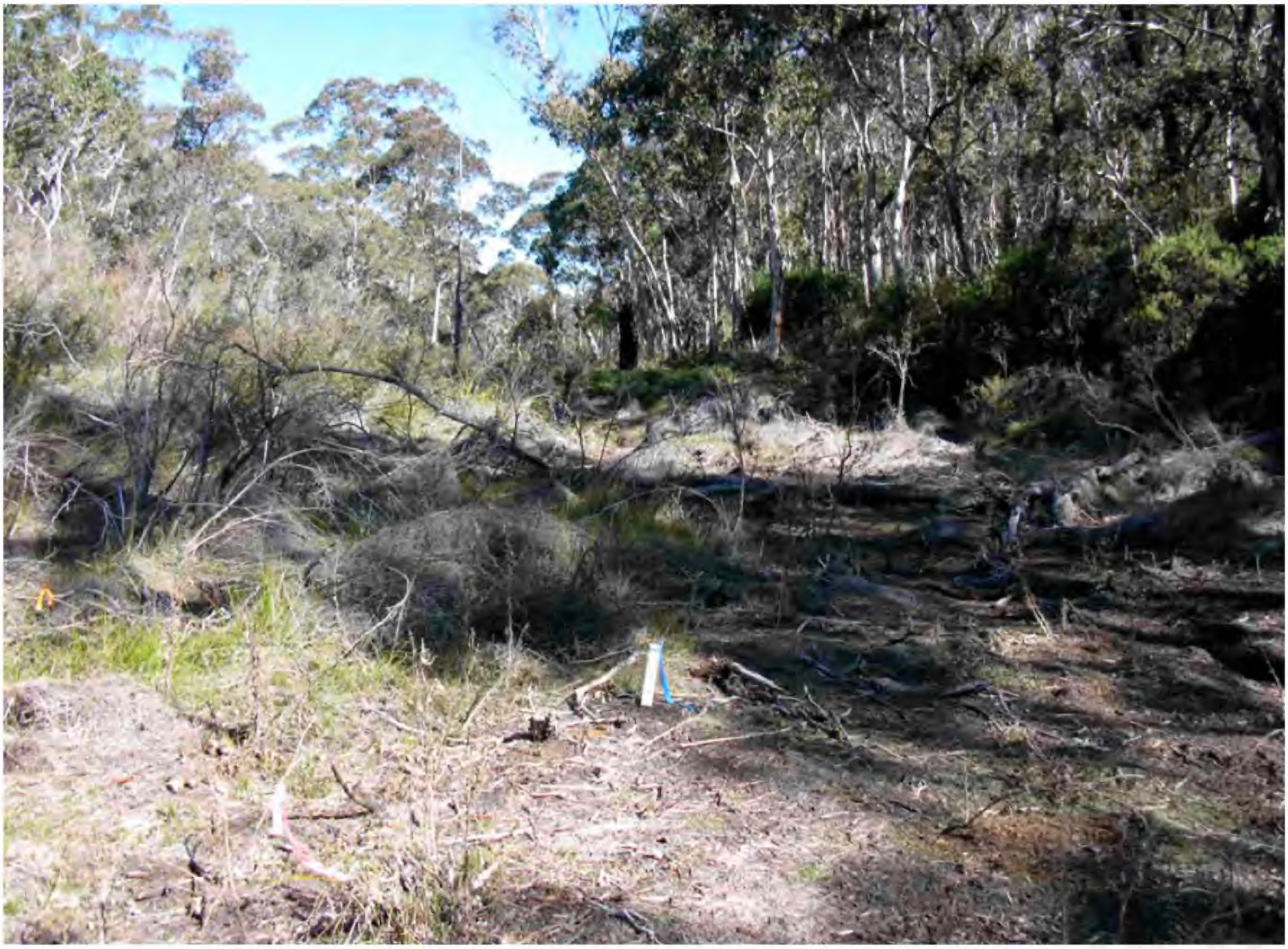


**Fig. 4.** East Wolgan Swamp in August 2011 showing dead vegetation and bare ground resulting from mining impacts (photo L. von Richter).

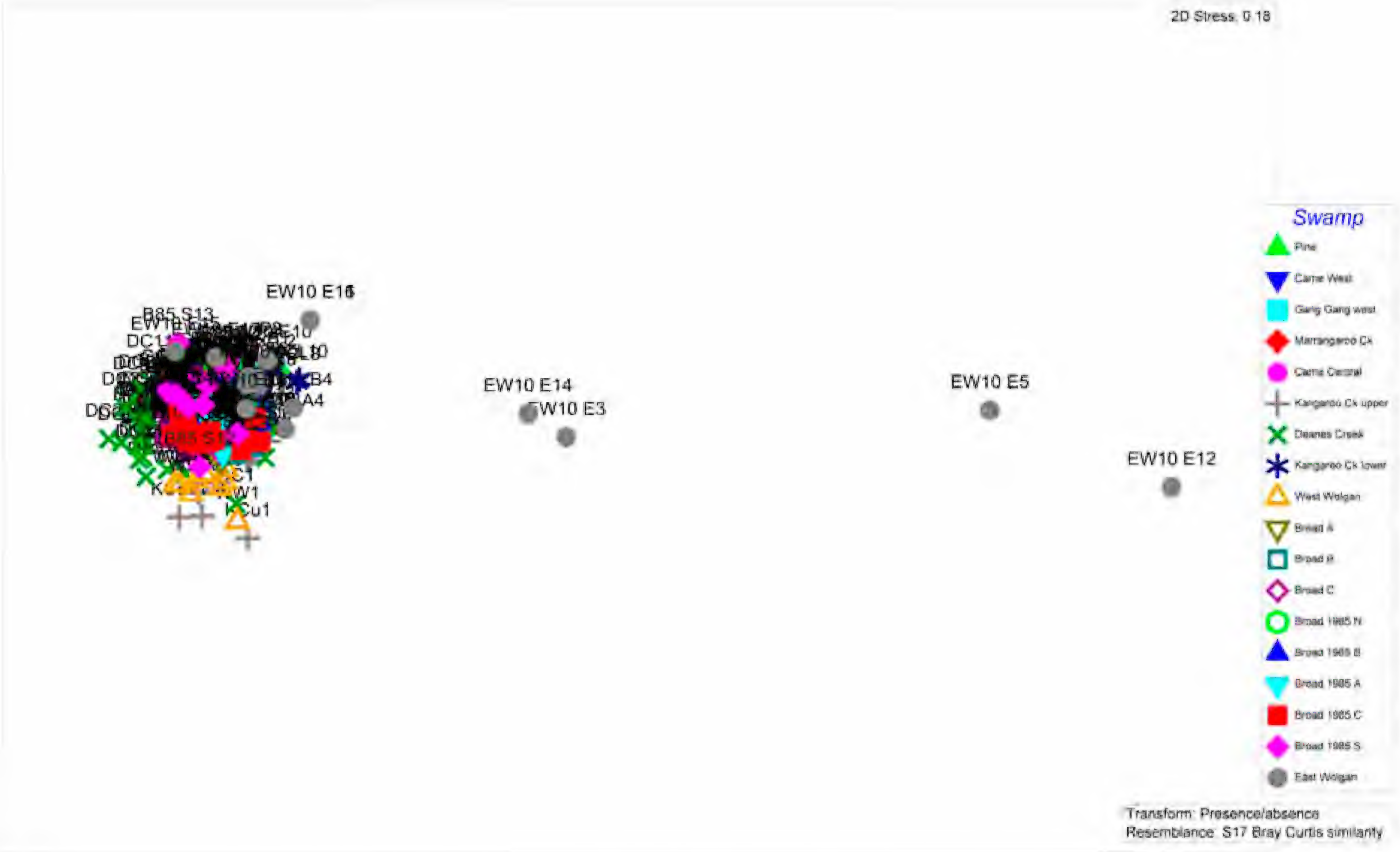
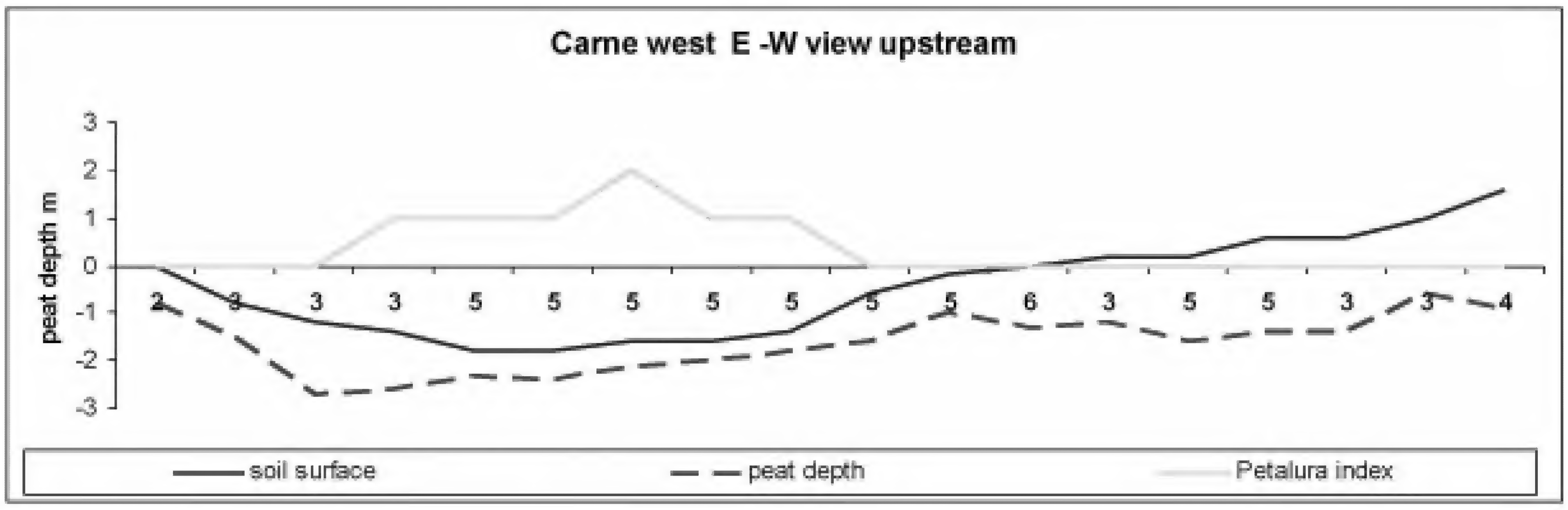
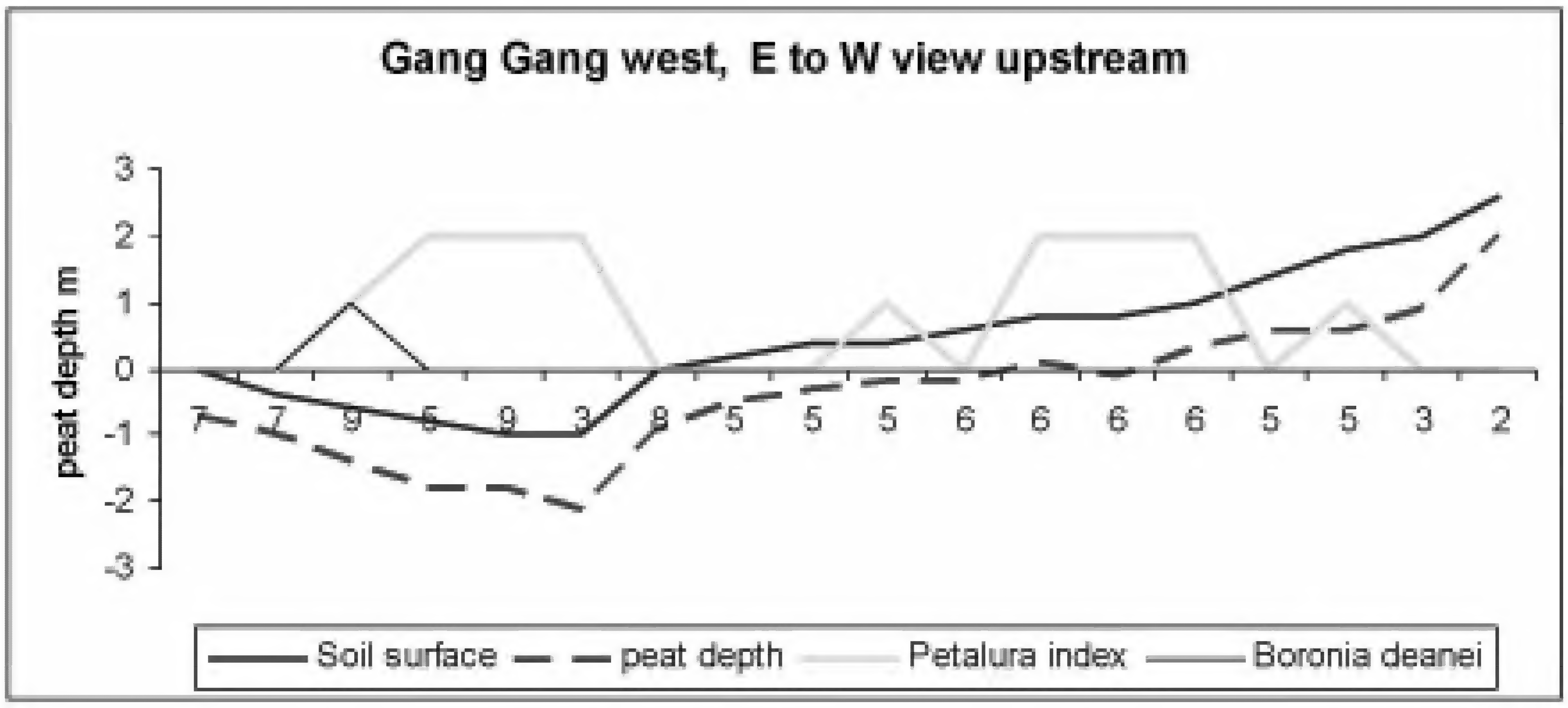


**Fig. 5.** Ordination position of East Wolgan plots (recorded 2010) in relation to data from all other swamps (including 1985 data for Broad Swamp).

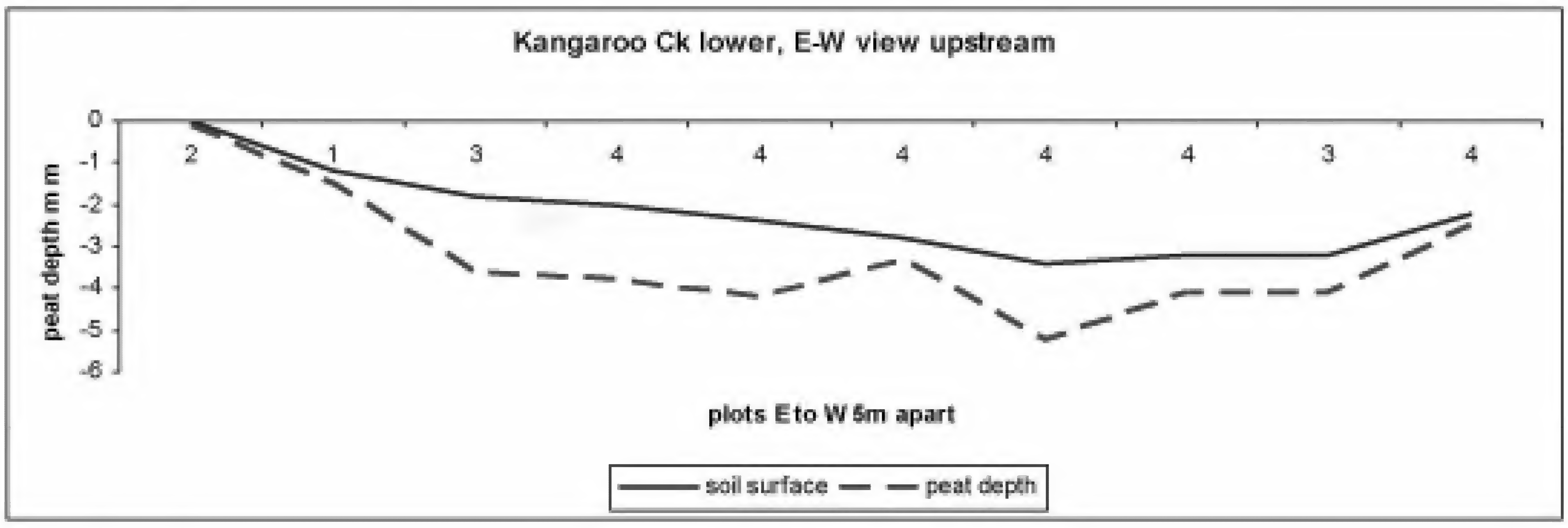
**6a**


Carne west E -W view upstream
peat depth m
3
2
1
0
-1
-2
-3
2
3
3
3
5
5
5
5
5
5
5
6
3
5
5
3
3
4
soil surface
peat depth
Petalura index

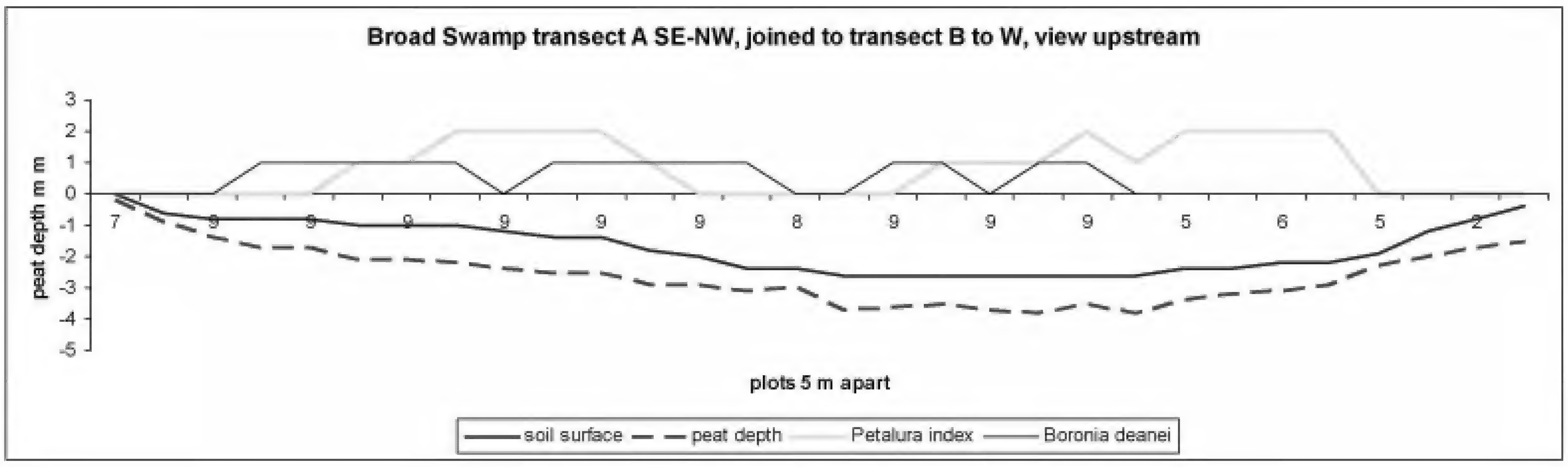
**6b**


Gang Gang west, E to W view upstream
peat depth m
3
2
1
0
-1
-2
-3
7
7
9
6
9
3
8
5
5
5
6
6
6
6
5
5
3
2
Soil surface
peat depth
Petalura index
Boronia deanei

**6c**


Kangaroo Ck lower, E-W view upstream
peat depth m m
0
-1
-2
-3
-4
-5
-6
2
1
3
4
4
4
4
4
3
4
plots E to W 5m apart
soil surface
peat depth

**6d**


Broad Swamp transect A SE-NW, joined to transect B to W, view upstream
peat depth m m
3
2
1
0
-1
-2
-3
-4
-5
7
9
9
9
9
9
9
8
9
9
9
5
6
5
2
plots 5 m apart
soil surface
peat depth
Petalura index
Boronia deanei

**6e**

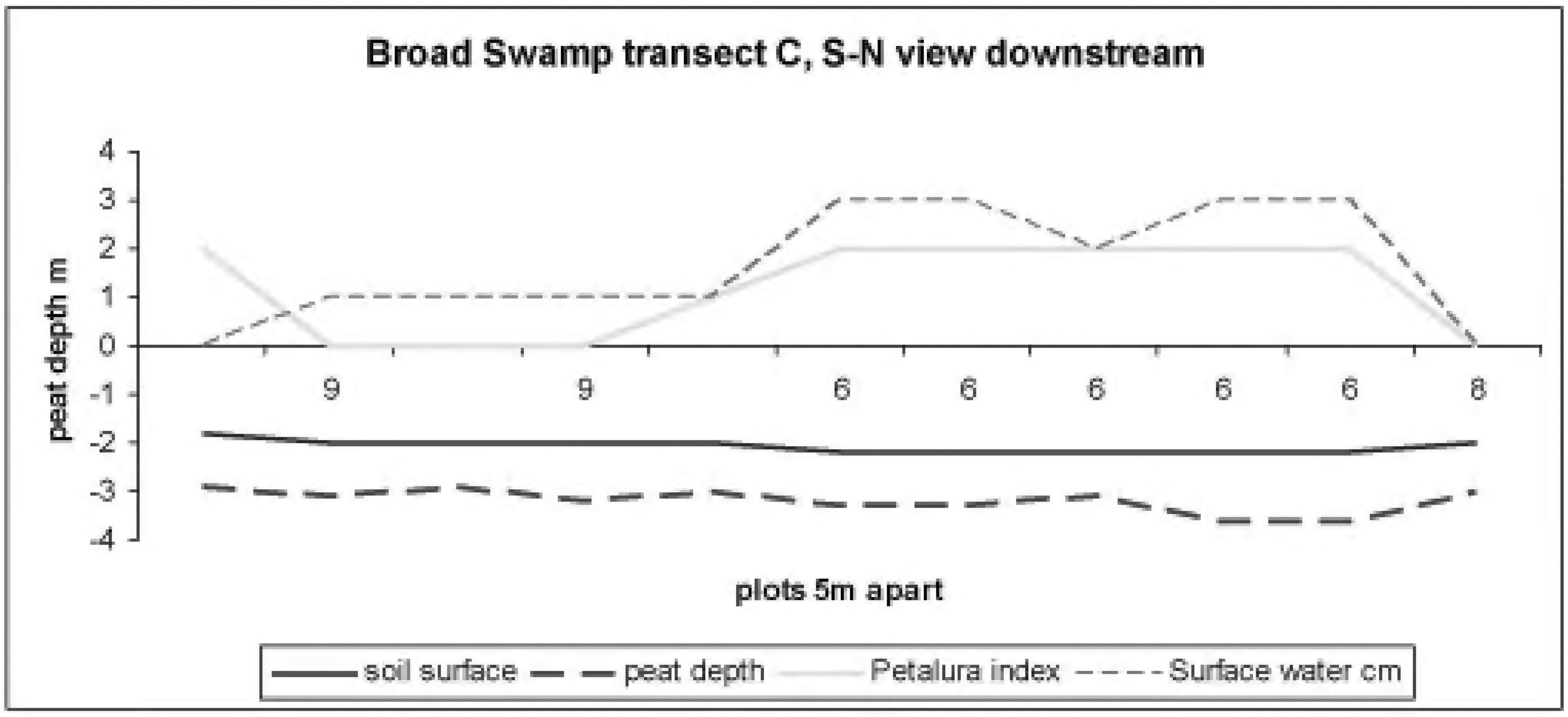


**Fig. 6a – e.** Cross-sections of Carne West, Gang Gang, Kangaroo Creek Lower and Broad Swamps (2 transects) showing PATN site groups (Figure 7) in relation to surface topography and peat depth.

substantial erosion and transport of upslope sediments into the swamp system as either overland flow from adjoining forest or woodland, or along drainage lines. Typically, the basal layer was composed of dense material, which was presumed, based on the experience of the authors, to be either sands or sandy clays deposited prior to development of the overlying more organic rich peatland soil layers at the probe location. However, it should not be assumed that these basal sediments are necessarily indicative of the earliest date for initiation of swamp sedimentation, as episodic disturbance events (severe fire and/or drought followed by severe erosion) may result in localised loss of swamp sediments through erosion.

In the 1980s the eastern swamps were generally wet underfoot. In 2008–10, following a decade of relatively dry climatic conditions, they were generally dry underfoot except along main surface water channels. In 2012 all parts of the Carne/ Clarence/ eastern swamps had moist subsoil, and all swamps had some overland flow. While most of these swamps have a main drainage line, side drainage lines also provide significant water and areas of surface waterlogging. Some vegetation patterns are related to current surface topography with surface drainage lines following low-lying sections of the swamp.

### *Vegetation patterns within the Carne/Clarence/eastern swamps*

Data from the seven Carne/Clarence/ eastern swamps (99 plots x 55 species, presence/absence data) were analysed separately and interpreted through a PATN two-way table at 10 group level (Figure 7, Table 2). Plots in these swamps are united by all having the almost ubiquitous small sedge *Empodisma minus* (except Pine swamp Group 1 which is affected by adjacent pine plantations, and some Woodland edge plots – Group 2). *Empodisma* is generally associated with peat swamps, and with permanent longterm moisture, and occurs widely in swamps from sea level to alpine areas. It is also the main peat-forming species in ombrotrophic mires in New Zealand (Agnew *et al* 1993) (where it also occurs with *Gleichenia*), and is likely to be a major peat forming species in NPSS.

The 99 plots are more or less evenly divided on the presence of *Gleichenia dicarpa*, an easily recognisable rhizomatous groundfern generally indicative of permanent moisture, and associated with soaks and seepage areas, but not tolerant of longterm or permanent standing water. *Gleichenia* requires high light levels and damp ground, preferring situations where its roots are wet and its fronds are in the sun. It colonises disturbed seeping ground and requires constant moisture to survive. Mature plants do not respond well to disturbance. Five site groups with *Gleichenia* are recognised; *Gleichenia – Blechnum* fernfield (Pine Swamp plots probably affected by adjacent pine plantation shading/competition), Woodland intrusion/ margin plots, two *Gleichenia – Empodisma* fernfield units (depending on presence or absence of surface water), and *Baeckea* shrubland. These plots all tend to be in the narrower swamps.

The 5 site groups without *Gleichenia* are; a Woodland intrusion/margin group (7), and a group (8) with similar species (including *Velleia montana*) associated with shallow peat over “interfluve ridges”. The other three groups are associated with surface water and deep peat. Of these, Shrub-rich swamp (9), including almost all occurrences of *Boronia deanei,* is restricted to large embayments in Broad swamp, where surface water is likely to depend on rainfall events (such areas were very dry during the recent drought). Buttongrass sedgeland (6) was related to main drainage lines which are likely to have more permanent flows. *Empodisma* dominated sedgeland (10) was only found in Carne Central swamp, which has a much shallower and less concave surface profile than the other deep swamps (mean surface

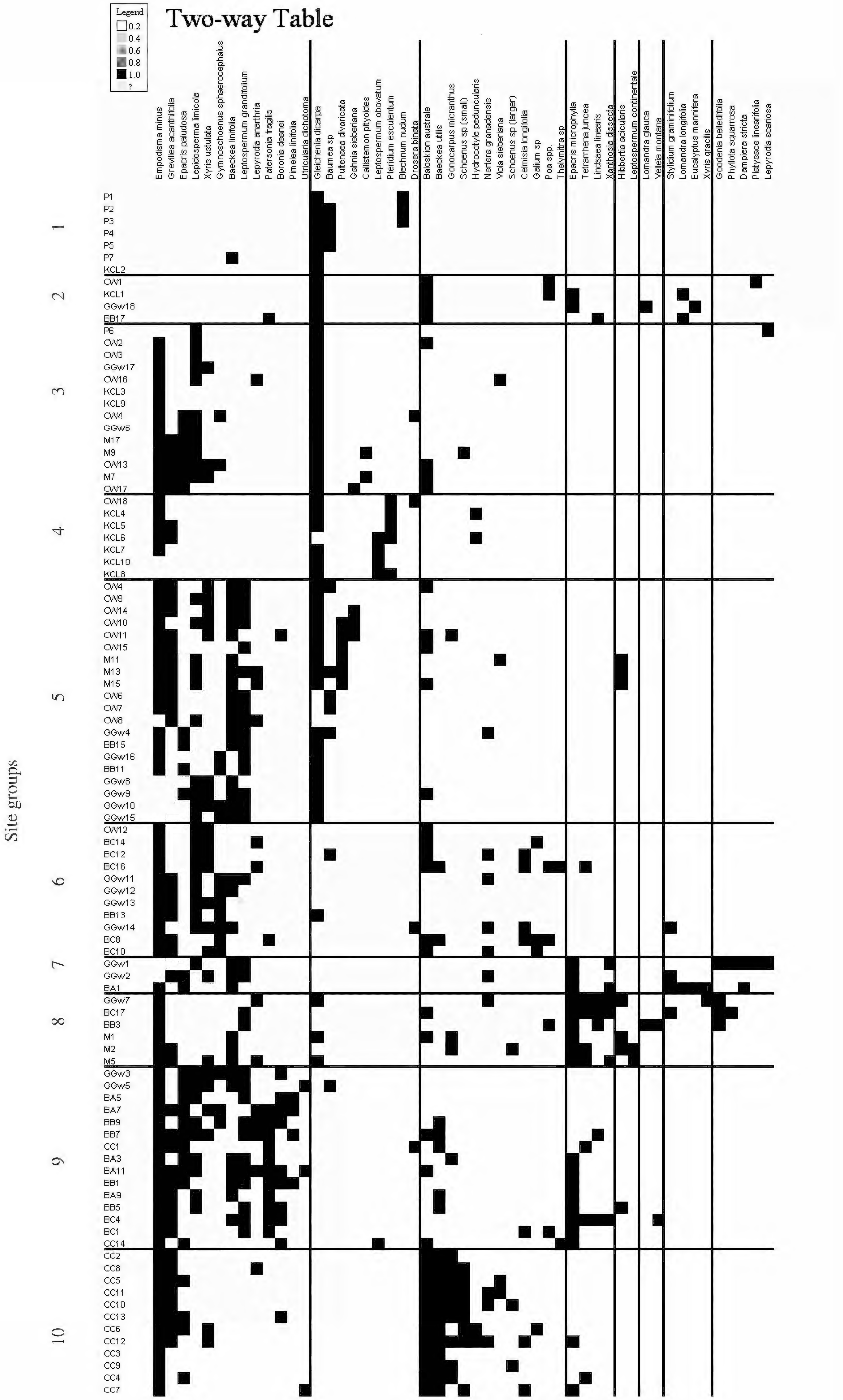


**Fig. 7.** PATN two-way table (99 plots x 55 species) showing 10 site groups with related species composition. (see also Figure 6 and Table 2)

**Table 2. Site groups (from PATN analyses) for 99 plots in seven Carne/ Clarence/eastern swamps, showing occurrence of *Empodisma* and *Gleichenia*, associated species, plot parameters means (KW values), possibly attributable as state/transition components.**

| ***Empodisma* present** | ***Gleichenia* present** | **Plot conditions** | **Peat thickness** | **Other species** | **PATN site group** | **Notional state/ transition name** | **Percent of plots** | **Mean Petalura index 0-2** | **Mean distance from edge m** | **Mean surface water depth cm** | **Mean peat thickness m** | **Mean surface depression m** | **Mean rock presence 0-1** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | + | Edge plots | shallow | *Baloskion* | 2 | Woodland margin intrusion | 4% | 0 | 1.3 | 0 | 0.6 | 0.6 | 0 |
| 0 | + | Pine Swamp | deep | *Blechnum,* few species | 1 | *Blechnum* fernland | 7% | 0 | 6.4 | 2.9 | 1.1 | 0.9 | 0 |
| + | + | Dry surface, Kangaroo Ck Lower | shallow | *Leptospermum obovatum,* few others | 4 | *Gleichenia -Empodisma* fernland | 7% | 0 | 11.4 | 0 | 0.6 | 2.3 | 0.3 |
| + | + | Surface water, | shallow | *Grevillea acanthifolia, Baeckea linifolia, Leptospermum grandifolium* | 5 | *Baeckea/Leptospermum grandifolium* shrubswamp | 20% | 0.9 | 26.3 | 3.6 | 0.7 | 2.2 | 0.1 |
| + | + | Surface water | deepest | *Grevillea, Lepidosperma limicola* | 3 | *Gleichenia -Empodisma* fernland | 14% | 0.2 | 13.6 | 0.5 | 1.2 | 1.8 | 0.1 |
| + | 0 | Edge plots, shallow, dry | shallow | *Baeckea linifolia, Epacris microphylla, Xanthosia dissecta, Stylidium* | 7 | Woodland margin intrusion | 3% | 0 | 1.7 | 0 | 0.5 | 1.9 | 0 |
| + | 0 | Surface water | deep | *Grevillea, Lepidosperma, Gymnoschoenus* | 6 | Buttongrass swamp | 11% | 1.6 | 26.4 | 1.6 | 1 | 2 | 0.6 |
| + | 0 | Surface water, deep peat, non-edge, not main channel | deep | *Grevillea, Epacris paludosa, Patersonia, Boronia deanei, Leptospermum grandifolium, Lepidosperma, Epacris microphylla* | 9 | Shrub-rich swamp | 15% | 0.7 | 35.3 | 0.7 | 0.9 | 1.8 | 0.4 |
| + | + | Dry, non-edge, shallow peat | shallow | *Epacris microphylla, Baeckea linifolia, Gleichenia* | 8 | Intra-swamp ridge species | 6% | 0 | 21.7 | 0 | 0.8 | 1.5 | 0 |
| + | 0 | Deep surface water, shallow surface depression, Carne Central swamp | deepest | *Grevillea, Baloskion, Baeckea utilis, Gonocarpus micranthus* | 10 | *Empodisma* sedgeland | 12% | 1.8 | 17.5 | 6.1 | 1.2 | 0.6 | 0.1 |
|  |  |  |  |  |  |  | KW value | 38.4 | 37.1 | 31.7 | 31.6 | 26.6 | 9.9 |

depression 0.6 m compared to 1.8 m (Group 3) to 2.2 m Group 5), and may have an impact on subsurface moisture movement perhaps resulting in shorter periods of saturation. Group 10 had the highest surface water depth (mean = 6 cm), the highest incidence of *Petalura* occurrence and the deepest peat (mean = 1.2m).

There are clearly relationships between site/species groups and surface/subsoil moisture conditions, and swamp physiographic conditions (Figure 6). The fieldwork was carried out after a particularly wet season and we could not assess how long surface water is likely to remain, though deep channels are likely to be permanent flows. Associations with peat depth are mainly evident at shallower depths, differences in depths greater than 1 m do not appear to have much direct effect, though there is little information about the importance of root depth for swamp species.

Notional state/transition names have been applied to the site/species groups but at this stage it is not clear how consistent and repeatable from swamp to swamp these units are. The major swamp species appear to be long-lived, and though their distribution relates to current physical properties, some features such as peat depth are likely to be permanent, but others, such as surface water depths are likely to vary depending on climatic conditions. Species composition in Woodland margin/intrusion sites may indicate relatively recent responses to disturbance regimes including fire, drought or sediment movement.

Overall, despite the potential spatial variation in hydrological characteristics within swamps the main core species of NPSS are surprisingly consistent. Long-lived, tall growing and mostly lignotuberous shrubs– *Grevillea acanthifolia*, *Epacris paludosa*, *Leptospermum grandifolium*, *Baeckea linifolia*, and rhizomatous graminoids *Lepidosperma limicola*, *Lepyrodia anarthria*, *Xyris ustulata* and *Gymnoschoenus sphaerocephalus* occur in most site groups, with the ubiquitous but shorter growing, *Empodisma minus.* Ecological attributes of the main plant species are shown in Table 3 but a better understanding of the individual ecology of these species, and particularly the rhizomatous fern *Gleichenia dicarpa*, which may be a key identifier of particular longterm water movement, is now needed.

**Table 3 Ecological attributes of main swamp plant species showing three clusters:- resprouters/distance dispersed; resprouters/local dispersal; short-lived/soil seedbank. (y=yes, n=no, ?=unknown)**

| Species | Family | long-lived soil seedbank | resprouts | long-lived | vegetative spread | large canopy | distance dispersal |
|---|---|---|---|---|---|---|---|
| **1) resprouters/ distance dispersal** | | | | | | | |
| *Baeckea linifolia* | Myrtaceae | n | y | y | n | ? | y |
| *Drosera binata* | Droseraceae | n | y | y | ? | n | y |
| *Gleichenia dicarpa* | Gleicheniaceae | n | y | y | y | y | y |
| *Leptospermum grandifolium* | Myrtaceae | n | y | y | n | y | y |
| *Juncus planifolius* | Juncaceae | ? | y | y | n | n | y |
| *Baeckea utilis* | Myrtaceae | n | y | y | n | n | ? |
| **2) resprouters/ local dispersal** | | | | | | | |
| *Boronia deanei* | Rutaceae | y | y | y | n | n | n |
| *Epacris paludosa* | Ericaceae | y | y | y | n | n | n |
| *Grevillea acanthifolia* | Proteaceae | y | y | y | n | ? | n |
| *Empodisma minus* | Restionaceae | ? | y | y | y | n | n |
| *Lepyrodia scariosa* | Restionaceae | ? | y | y | y | y | n |
| *Patersonia fragilis* | Iridaceae | ? | y | y | n | n | n |
| *Gonocarpus micranthus* | Haloragaceae | y | y | y | y | n | ? |
| *Gymnoschoenus sphaerocephalus* | Cyperaceae | ? | y | y | n | y | ? |
| *Lepidosperma limicola* | Cyperaceae | ? | y | y | y | y | ? |
| *Lepyrodia anarthria* | Restionaceae | ? | y | y | ? | n | ? |
| *Baloskion australe* | Restionaceae | ? | y | y | y | n | ? |
| *Xyris ustulata* | Xyridaceae | ? | y | y | n | y | ? |
| **3) short-lived/ soil seedbank** | | | | | | | |
| *Xanthosia dissecta* | Apiaceae | y | y | n | n | n | ? |
| *Epacris microphylla* | Ericaceae | y | n | n | n | n | n |
| *Epacris obtusifolia* | Ericaceae | y | n | n | n | n | n |
| *Pimelea linifolia* | Thymelaeaceae | y | n | n | n | n | n |
| *Sprengelia incarnata* | Ericaceae | y | n | n | n | n | n |
| *Viola hederacea* | Violaceae | ? | n | y | y | n | ? |
| *Gonocarpus tetragynus* | Haloragaceae | y | ? | n | n | n | ? |

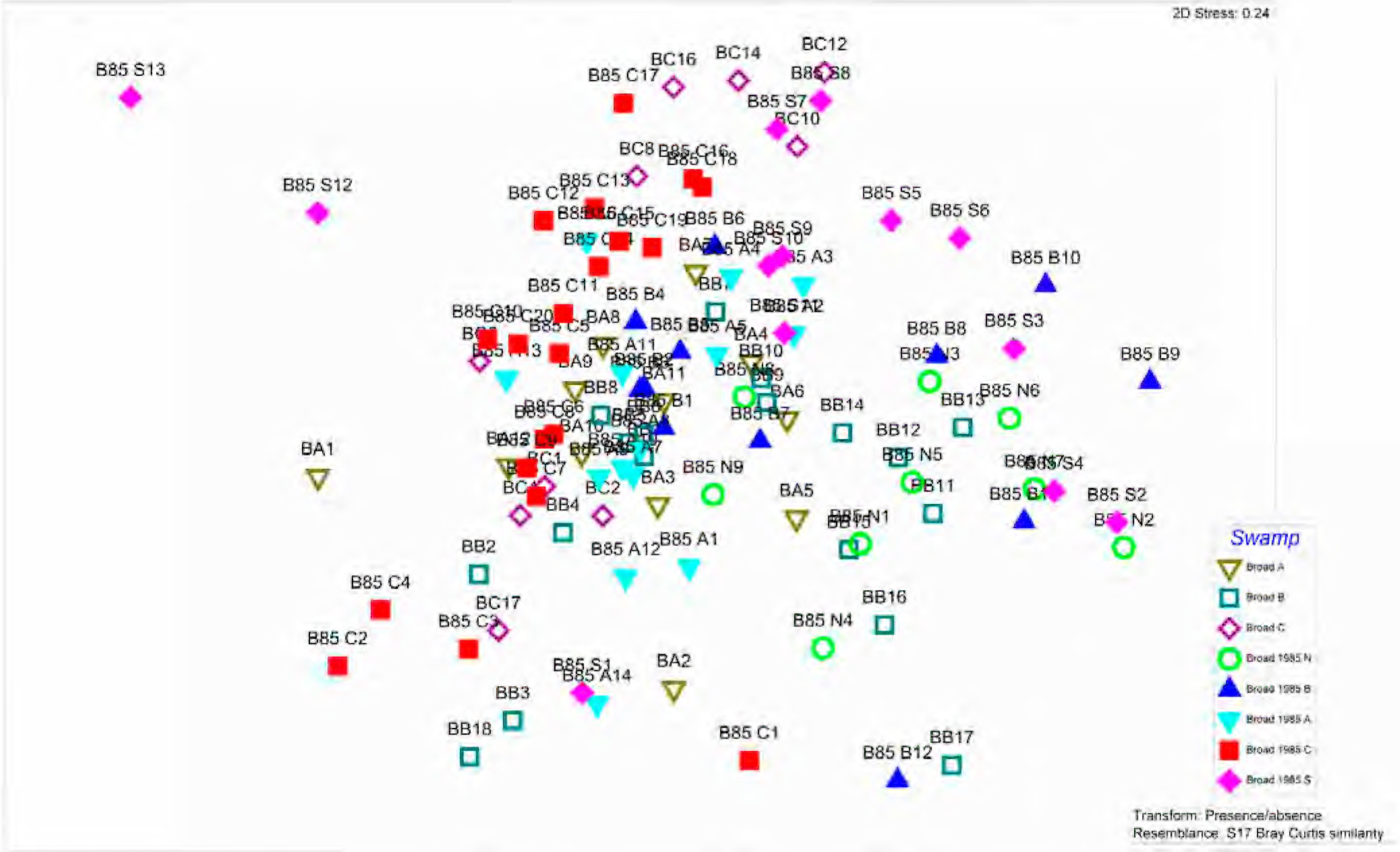


**Fig. 8.** Ordination of plots from Broad Swamp in 1985 (closed symbols) and 2012 (open symbols) shows a similar spread of plots for both time periods indicating stable vegetation. Transects A, B and C correspond, but N and S were not remeasured in 2012.

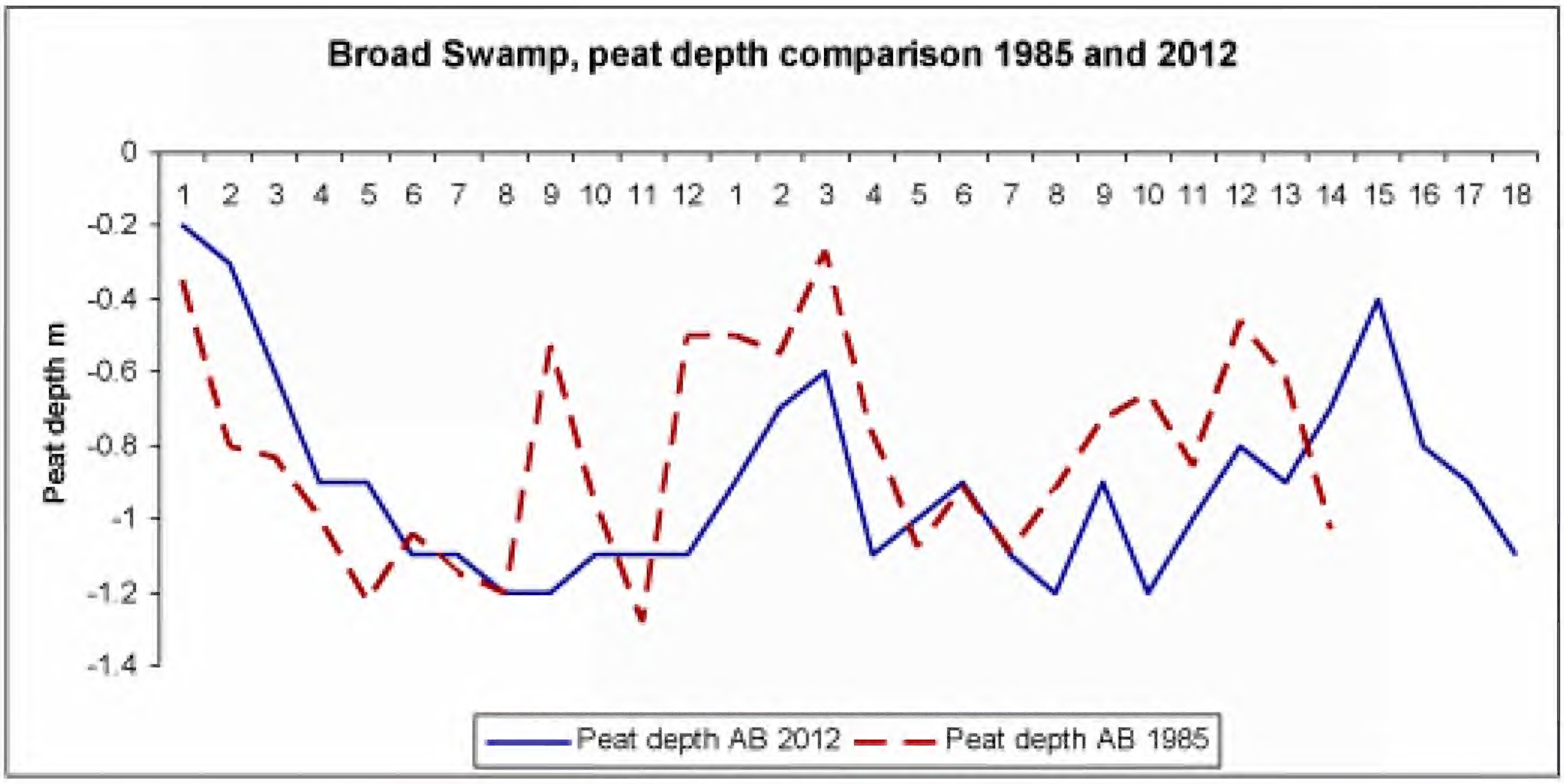
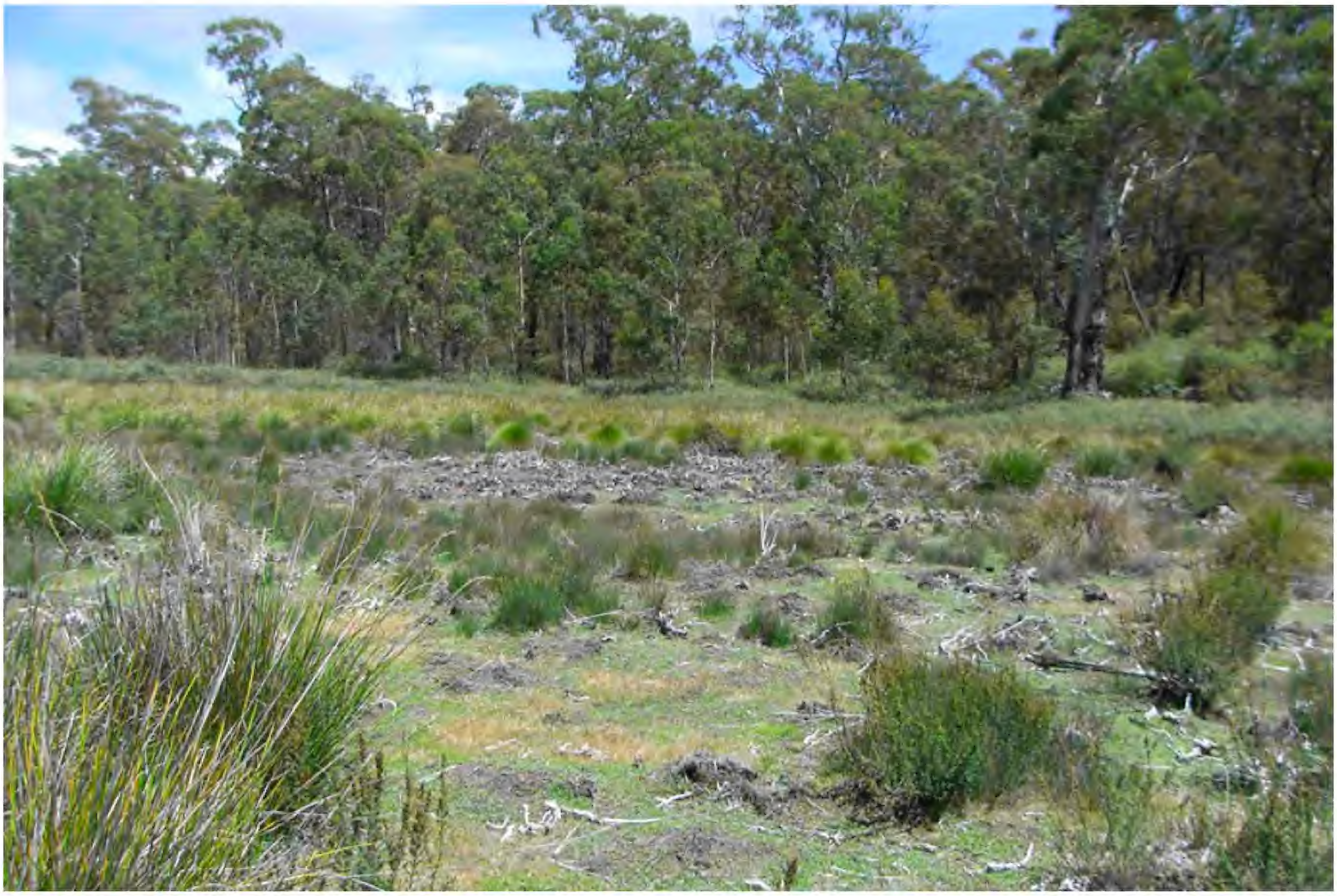
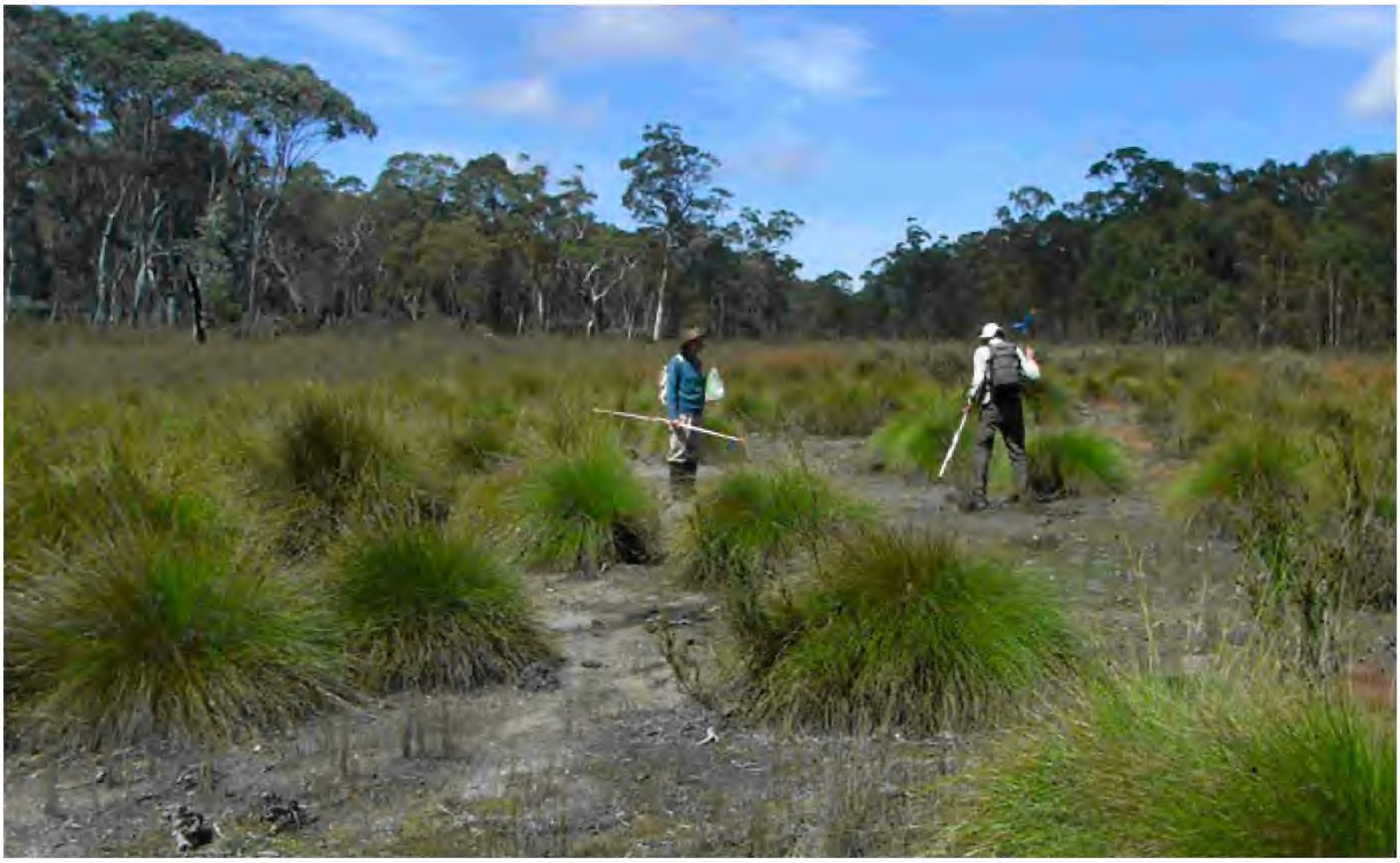


**Fig. 9.** Peat depths in Broad Swamp recorded across the main channel along Transects A and B in 1985 (dotted) and 2012 show surprising correspondence, evidence of the stability of the system



**a**



**b**

**Fig. 10.** Deanes Swamp in 2012, showing **a)** dead lignotubers (probably *Baeckea utilis* and *Leptospermum grandifolium*) evidently resulting from a large fire in Summer 2003, a period of very dry weather; and **b)** *Gymnoschoenus* clumps in centre of swamp. The previous fire at Deanes was a hot fire in 1982-83.(photos L. von Richter).

### *Comparison of 1985 and 2012 vegetation transects*

A combined ordination of plots from Broad Swamp in 1985 and 2012 shows a similar spread of plots from the two time periods, with transect locations showing broad correspondence, despite only approximate positioning of the 2012 transect in relation to the 1985 ones (Figure 8). As well, the peat depths recorded along Transect AB show surprising correspondence between 1985 and 2012, indicating the stability of the subsurface conditions (Figure 9). The result indicates stable vegetation with little change over the 27-year interval. The vegetation patterns in the swamps are likely to be relatively fixed depending on long-term groundwater and peat conditions. Most species resprout after fire from lignotubers or rhizomes and likely to be very long-lived (Table 3). A few are capable of vegetative spread, some have long-lived soil seedbanks, and there are many we don't know much about. There does not appear to have been any fire over that time for the swamps studied except Deanes Swamp. However Deanes Swamp had an extensive area of dead lignotubers (probably *Baeckea utilis* and *Leptospermum grandifolium*), evidently resulting from a large fire in Summer 2003 (NP&WS fire records), a period of very dry weather. Deanes Swamp is also at a lower elevation than the other swamps and likely to receive lower rainfall. The previous fire at Deanes was a hot fire in 1982–83 (Figure 10).

### *Threatened swamp-dependent biota*

All the Newnes Plateau records for the swamp-dependent biota *Petalura gigantea* (Baird 2012), *Eulamprus leuraensis* (NSW Wildlife Atlas, excluding several possibly inaccurate locations) and *Boronia deanei* (National Herbarium of NSW and this study) have been listed (Table 4). While overall ranges of the taxa are not coincident there is a concentration of them in the swamps in the eastern Newnes Plateau, particularly in the Carne, Bungleboori, Rocky, Budgary and Farmers Creek catchments. Within an individual swamp they may however occupy different microhabitats. For example, *Petalura* and *Boronia* both occur in Gang Gang West, Carne Central and Broad Swamp, with relatively little overlap of habitat except in Broad Swamp, though here the *Petalura* habitat is more extensive (Figure 4 b,d,e; Appendix 1 e,h,i,j). Notes on the distribution and ecology of individual species follow.

### *Boronia deanei subsp. deanei*

On the Newnes Plateau *Boronia deanei* is restricted to swamps in upper Carne Creek and to some in upper Farmers Creek and upper Wollangambe River (Table 4, Figure 2g). It is generally a locally abundant species where it occurs, and in flower its extent can be recognised at a distance by the conspicuous pink coloured patches (e.g. notable in Broad swamp in November-December 2009). Similarly its absence can be inferred at the same time (it was absent from the similar structured Browns Swamp despite searches in 1980s, and in 2008–9 in the Dargans Creek catchment).

Of the 10 swamps with transects, *Boronia deanei* occurred in three, all in the Carne Creek catchment, though abundance from swamp to swamp varied with frequency of occurrence along transects being 5% in Gang Gang West (1/18 plots), 14% in Carne Central (2/14) and 35% in Broad Swamp (14/40). At these plots peat thickness ranged from 0.7–1.2 m deep (mean=0.97 +/- 0.04), with surface water recorded at 8 of 17 plots, with depths up to 6 cm (generally there is still some surface water present in all but the driest times- I Baird pers. comm.). *Boronia deanei* was associated with the Shrub-rich swamp group (Group 8 of PATN analysis).

Plant density in a typical dense population was 1.6 plants /0.25 m$^2$ (se= 0.4, n=10) (measured with a 0.25 m$^2$ quadrat). Individual plants were up to 1 m high with stem thickness at base up to 2 cm. Plants are generally multi-stemmed. No seedlings or small juvenile plants were noted recently or in searches made after fire events in the 1980s (D. Benson pers. obs.) despite the abundance of adult plants. *Boronia deanei* occurrences were in the *Epacris microphylla* heath, but also in the drier end of the wet heath and in the marginal sites with deep soil.

Recent remote sensing by Fletcher and Erskine (2012) confirms the limited occurrence of *Boronia deanei* on the Newnes Plateau. They report 58 distinct populations covering 5.08 ha within five swamp communities in Carne Creek catchment with individual clusters ranging from <10 m$^2$ to >0.5 ha, but only 3 populations covering more that 4046 m$^2$ (1 acre).

### *Petalura gigantea*

*Petalura gigantea* has been recorded from a number of Newnes Plateau Shrub Swamps, with potential breeding habitat identified in others (Baird 2012) (Table 4). Extensive burrow investigations and observation of hundreds of oviposition and burrow locations across a range of mire types in the Blue Mountains (2003–2011) (Baird 2012) confirm *Petalura gigantea* as an obligate, groundwater dependent, mire-dwelling species. All observed oviposition occurred into waterlogged substrate, fissures in the substrate, amongst or under moist litter overlying the substrate, amongst roots at the base of plants in moist substrate, or into *Sphagnum*.

*Petalura* burrow depth was recorded to range from 18 to 75 cm (the deepest depth recorded for a petalurid larval burrow), with a mean depth of 37 cm (n = 27) (seven burrows < 30 cm, seven burrows > 39 cm, one burrow > 60 cm). Figure 11 shows a typical larval burrow. In some cases, burrows terminated when larvae encountered bedrock or dense sands and gravels overlaying the bedrock and in these cases, adaptive burrowing deepening in response to a lowering water table would be impossible. All burrows were characterised by the presence of groundwater and burrows are occupied for the duration of the larval stage. As currently understood, this period is at least 6 years, but may extend beyond 10 years. The recording period (2003–2011) began at the end of a major drought and continued into wetter conditions. These burrow measurements thus confirm that regardless of short-term fluctuations associated with rainfall events, and evidence of some adaptive burrow deepening putatively associated with a lowering water table during the drought period, that groundwater levels in these swamps are relatively stable over long periods. This is backed up by piezometer level measurements in Sunnyside and Carne West swamps (Centennial Coal 2009, DECCW 2010b).

A number of burrows showed evidence of adaptive burrow deepening during a period of drought. In these situations there was a descending burrow section (with a terminal chamber) that had been excavated below what appeared to be a previously established terminal chamber. This behaviour was assumed to be a response of larvae to a lowering of the water table across a number of years since burrow establishment. This observation further suggested obligate groundwater dependence in the species and is consistent with documented observations of groundwater in burrows of other fossorial petalurids within Australia and Internationally (*Petalura hesperia*, *Uropetala* spp., *Tanypteryx* spp.). This assumption was supported by the observation that in a large proportion of burrows, the depth of one of the lateral chambers effectively coincided with the water level within the burrow at the time of excavation. A high proportion of burrows had more than one lateral chamber, which also suggested adaptation associated with changing groundwater levels. In terms of larval ecology, this also suggested an important functional relationship between these lateral chambers and the water table (Baird 2012).

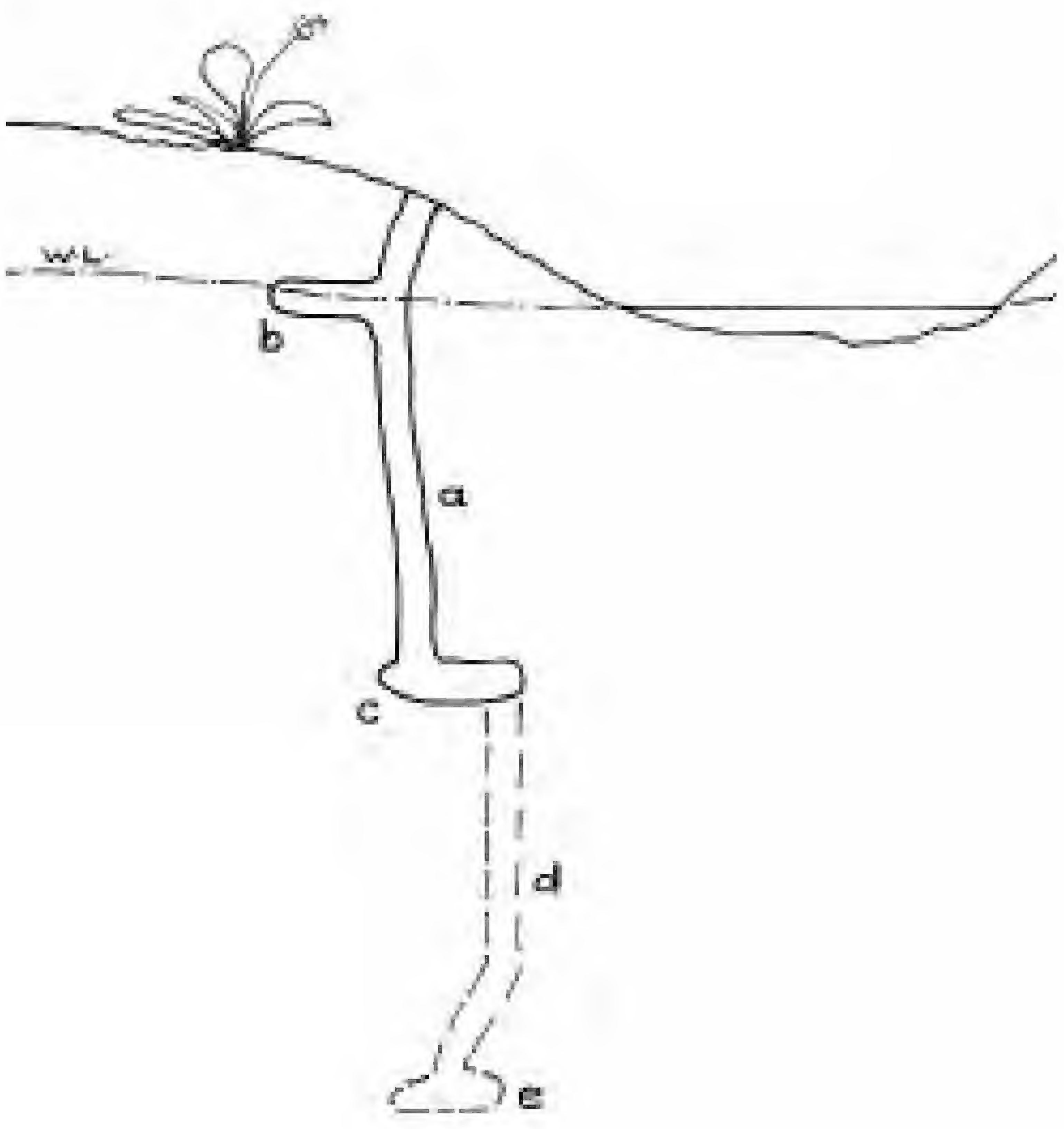


**Fig. 11.** Illustration of a simple larval burrow of *Petalura gigantea*, showing water level (W.L.), descending burrow section **(a)**, single lateral chamber **(b)** and terminal chamber **(c)**. Putative adaptive burrow deepening with secondary descending burrow section **(d)** and new terminal chamber **(e)** shown (dashed line).

*Eulamprus leuraensis*

All swamps where *Eulamprus* has been recorded are characterised by the presence of permanent groundwater seepage or waterlogging in at least part of the swamp (including during drought), and typically include small, often braided, perennial seepage streamlets. While some of these seepage streamlets may lose surface water during drought, the drainage lines are still characterised by the presence of a shallow water table and at least moist substrate surface in localised areas. *Eulamprus leuraensis* may be observed anywhere within these swamps, but is observed most frequently (during spring and summer when active) in association with more waterlogged areas, and sometimes in water during hot weather.

*Euastacus australasiensis*

*Euastacus* is widely distributed in NPSS, occurring in the typical valley floor swamps and occasional valley side swamps, where conditions are suitable, and appears to be restricted to swamps with permanent groundwater seepage in at least part of the swamp. Larger burrows (of presumably larger and older individuals) may be located away from the wettest parts of the swamps, but are presumed to connect to the watertable. Burrows are more frequently observed, however, in waterlogged seepage areas and along perennial seepage streamlets, which frequently drain these swamps. Excavated material associated with burrow deepening or maintenance frequently includes quartz pebbles and mineral soils, which may be associated with basal sediment layers deposited prior to peatswamp formation (in addition to intermediate layers associated with subsequent deposition events). Burrows of juvenile crayfish appear to be restricted to the wetter areas, often associated with emergent groundwater seepage, and are difficult to differentiate from burrows of *Petalura gigantea* larvae.

*Dillwynia stipulifera*

Plants of *Dillwynia stipulifera* were very infrequently recorded along transects and it appears to be a very rare species in the swamps. In view of its limited occurrence and threats to its swamp habitats it would appear that there may be a good case for listing it as a threatened species as well.

*Rulingia prostrata*

Our survey also recorded the TSC Act listed Endangered prostrate plant species *Rulingia prostrata* (family Sterculiaceae) in Deanes Creek Swamp, the first recording of this species in the Blue Mountains, though it has been previously recorded from THRPS listed swamp sites in Penrose State Forest area. Unlike the other listed species its ecological habitat appears to be swamp margins where it germinates in sites made bare by dry conditions. Deanes Creek Swamp was the lowest elevation swamp we surveyed.

## Discussion

### *Swamp classification*

In their mapping of the swamps of the Newnes Plateau, Benson and Keith (1990) grouped all permanent swamps together as NPSS, but noted that swamps on the western side of the plateau (e.g. West Wolgan, Kangaroo Creek-Upper) tend to be drier and have a greater component of *Leptospermum* shrubland, perhaps indicative of less-permanently high watertable (perhaps more rainfall-dependant than groundwater dependant). Distinctions between 'dry' and 'wet' swamps have been made in the context of potential impacts of subsidence from underground longwall mining (Aurecon 2009), implying that subsidence is unlikely to affect 'dry' swamps, and there is some evidence to suggest some of these swamps (e.g. West Wolgan -M. Krogh pers. comm.) may be less susceptible to subsidence impacts than the groundwater dependent swamps further east due to the lower level of incision of the drainage lines. However, as longwall mining is progressing from west to east (from the Wolgan River to Carne Creek catchments) the wetter swamps are now in line to be impacted.

**Table 4. Swamps on the Newnes Plateau (by decreasing elevation) with records of threatened swamp-dependent biota. All recorded and potential *Petalura gigantea* sites in Newnes Plateau Shrub Swamps (IRCB), with recorded presence of *Eulamprus leuraensis* (NSW Wildlife Atlas), and *Boronia deanei* and *Dillwynia stipulifera* (National Herbarium and fieldwork records - DHB).**

| **Swamp name** | **1:25k map** | **Easting** | **Northing** | **Drains to** | **Altitude m** | ***Petalura gigantea*** | ***Eulamprus leuraensis*** | ***Boronia deanei*** | ***Dillwynia stipulifera*** |
|---|---|---|---|---|---|---|---|---|---|
| Junction Swamp | Li | 235860 | 6302770 | Wolgan | 1160 | | | | |
| Kangaroo Ck Upper | Li | 235200 | 6302400 | Coxs | 1130 | | | | |
| West Wolgan | Li | 234600 | 6304750 | Wolgan | 1130 | | | | |
| Sunnyside | CB | 237834 | 6304082 | | 1120 | Recorded | | | |
| - tributary of Farmers Creek | Li | 239108 | 6296549 | Farmers | 1110 | potential | | | |
| Marrangaroo Creek | Li | 239105 | 6299040 | Marrangaroo | 1100 | potential | | | |
| Carne West | Li | 239179 | 6302913 | Carne | 1090 | Recorded | | 2010 | |
| Pine | Li | 241700 | 6300900 | Bungleboori | 1090 | | | | |
| Farmers Creek | Li | 241600 | 6295200 | Farmers | 1080 | | | | 1989 |
| Browns | Li | 242605 | 6292840 | Dargans | 1080 | potential | | ?1906 | |
| Paddys | Li | 241255 | 6298915 | Bungleboori | 1080 | potential. | | 1981 | 1981 |
| Carne Central | Li | 241200 | 6302500 | Carne | 1080 | potential | Recorded | 2012 | |
| Kangaroo Ck Lower | Li | 233250 | 6304300 | Coxs | 1080 | | | | |
| East Wolgan | CB | 236500 | 6304395 | Wolgan | 1080 | | | | |
| Narrow | CB | 236100 | 6305250 | Wolgan | 1080 | | | | |
| Happy Valley Springs | Li | 241639 | 6297024 | Farmers | 1075 | Recorded | Recorded | 1981 | 1981 |
| Gang Gang West | Li | 239997 | 6302962 | Carne | 1070 | Recorded | | 2012 | |
| Dargans Creek | Li | 243105 | 6293290 | Dargans | 1070 | potential | | | 1970 |
| North Pine | Li | 242007 | 6301239 | Bungleboori | 1070 | potential | Recorded | | |
| Sunnyside east | Li | 239230 | 6303710 | Carne | 1070 | potential | | | |
| Gang Gang East | Li | 240470 | 6303124 | Carne | 1055 | Recorded | Recorded | 2009,10 | |
| Murrays | Li | 243132 | 6303138 | Carne | 1055 | potential | Recorded | 2010 | |
| Broad Swamp | Li | 242005 | 6302840 | Carne | 1055 | potential | Recorded | 1985,10,12 | 2012 |
| Upper Dingo Creek | Li | 244409 | 6302518 | Bungleboori | 1030 | Recorded | | | |
| - | CB | 244092 | 6306029 | Carne | 1020 | Recorded | | | |
| Upper Dingo Creek | Wo | 244882 | 6303775 | Bungleboori | 1015 | Recorded | | | |
| - | CB | 237255 | 6311790 | Carne | 1010 | potential | | | |
| Upper Dingo Creek | RH | 244970 | 6304199 | Bungleboori | 1000 | Recorded | | | |
| Budgary Creek | RH | 246519 | 6308150 | Lower Wolgan | 980 | Recorded | Recorded | | |
| - | RH | 247445 | 6307058 | Bungleboori | 975 | Recorded | | | |
| Rocky Creek | RH | 245260 | 6309048 | Lower Wolgan | 975 | Recorded | | | |
| - Upper Dinner Gully swamp | RH | 247742 | 6308591 | Lower Wolgan | 960 | Recorded | Recorded | | |
| - | RH | 247991 | 6307307 | Bungleboori | 955 | Recorded | | | |
| Deanes Creek | RH | 244705 | 6314190 | Lower Wolgan | 940 | potential | | | |
| - | RH | 246675 | 6316893 | Lower Wolgan | 925 | potential | | | |
| - | RH | 249172 | 6310109 | Lower Wolgan | 835 | Recorded | | | |

Our analyses confirm that across the plateau rainfall and geomorphology relate to the occurrence of a cluster of swamps characterised by a high water table, more or less permanent moisture conditions and the associated development of peaty substrate up to 2 m deep. These groundwater dependent swamps are concentrated on the eastern half of the Newnes Plateau, including those in the headwater creeks of Carne, Bungleboori, Budgary, Rocky, Marrangaroo, Farmers, and some in Wolgan. The largest and most extensive swamps are in the headwaters of Carne Creek. These swamps are also the prime habitat for the particular groundwater dependent biota *Petalura gigantea*, *Eulamprus leuraensis* and *Boronia deanei* discussed below.

We also confirm that some of the western swamps (notably West Wolgan and Kangaroo Creek-Upper, and Sunnyside West) are distinctly different from the main body of groundwater dependent NPSS, have shallower and less developed peat, predominance of *Leptospermum* species, and are likely to be more rainwater dependent. However, there is not a simple east/west division. The floristic composition of the nearby Kangaroo Creek–Lower swamp on the western side, is closer to the groundwater dependent /permanent swamps than the nearby dry swamps. This may be related to groundwater dependence since a spring emanating from clay layers is observable in the creek bed immediately upstream of Kangaroo Creek–Lower swamp.

### *Groundwater-dependent biota*

The importance of groundwater and its function in maintaining the health and viability of many ecosystems has been recognised nationally (Clifton & Evans 2001; Davis *et al.* 2001; Eamus & Froend 2006; Hatton & Evans 1998; Murray *et al.* 2003) and in New South Wales (NSW Government 2002). Hatton and Evans (1998) have suggested that wetlands included the most diverse and extensive group of Australian ecosystems with groundwater dependency. Both Hatton and Evans (1998) and Clifton and Evans (2001) recognised five classes of ecosystem dependency on groundwater. Their class of *Ecosystems with proportional dependence on groundwater* appears to include all known and potential habitats for *Petalura gigantea*, *Eulamprus leuraensis* and other groundwater dependent species identified in this study. Such ecosystems are included within the Coastal Heath Swamps and Montane Bogs and Fens vegetation classes of Keith (2004). For these ecosystems Hatton & Evans (1998) suggested that 'it is likely that a unit change in the amount of groundwater will result in a proportional change in the health or extent of that ecosystem'.

When commenting on the level of groundwater dependency of wetland ecosystems, Clifton and Evans (2001) highlighted the importance of maintaining adequate groundwater levels in unconfined aquifers and adequate groundwater discharge flux for most wetland ecosystems to maintain the necessary level of wetness or waterlogging for key ecological stages: 'Changes in water table level may have important implications for these communities. Prolonged lowering or raising of the water table is likely to result in changes in species composition, favouring species adapted to drier or wetter conditions, respectively'. This dynamic may be critical to the long-term persistence of *Petalura gigantea,* because of its swamp or mire dependent fossorial larvae, the microhabitat requirements of ovipositing sites, the spatio-temporal distribution of such microhabitat within swamp patches, and the environmental tolerance of eggs and early larval instars. Changes in burrow groundwater quality or substrate attributes associated with temporal changes in groundwater depth may also play an important role in the persistence of this and other species (e.g. *Euastacus australasiensis*) within these wetlands. The International and Australian literature highlight the richness of groundwater dependent fauna and suggests that additional groundwater dependent fauna within these NPSS may potentially include stygofauna (e.g. Gilbert *et al.* 1994b; Humphreys 2008), pholoteros (e.g. Lake 1977; Suter & Richardson 1977), and/or other specialised spring (e.g. Hahn 2000; Hoffsten & Malmqvist 2000; Williams & Danks 1991), mire (e.g. Larson & House 1990; Mikkola & Spitzer 1983; Spitzer & Danks 2006) or moorland (e.g. Butterfield & Coulson 1983; Greenslade & Smith 1999) invertebrates.

Freshwater burrowing crayfish such as *Euastacus australasiensis* in upland swamps of the Sydney region, *Parastacoides tasmanicus* and *Engaeus leptorhyncus* in buttongrass *Gymnoschoenus sphaerocephalus* moorland of Tasmania (Richardson & Horwitz 1988; Richardson & Swain 1980, 1991;Horwitz *et al.* 1985); and *Cherax plebejus* in swampy seepages in southwest Western Australia (Horwitz & Knott 1983), have been identified as a significant component of Australian mire and moorland ecosystems. Groundwater filled crayfish burrows may provide fire and predation refugia for the Blue Mountains water skink *Eulamprus leuraensis*. *Parastacoides* spp. are known to increase respiration of surrounding soil in Tasmania (Richardson 1983), and may affect vegetation through soil aeration and root grazing within underground feeding chambers beneath plants (Richardson & Wong 1995).

*Petalura gigantea* burrows may also be similarly utilised by other species. For example, spiders, various insect taxa (e.g. Blattodea, Orthoptera), and a frog were observed within the entrance of a *Petalura gigantea* burrow (I.R.C. Baird pers. obs.). These diverse ecological relationships, and the shared reliance of different taxa upon groundwater, highlight the complexity of functional roles of these fossorial groundwater dependent organisms and their importance in these groundwater dependent ecosystems (GDEs).

The threatened shrub *Boronia deanei* and the rare shrub *Dillwynia stipulifera* are confined to the eastern NPSS and associated particularly with the extensive areas of moist peat in the broad swamps there. Drying of substrate resulted in death of adult plants in Murrays Swamp (in 2008–10) and no evidence of seedling recruitment has been noted despite increased rainfall. These two species have been observed to resprout following fire, though basal resprouting will be largely dependent on the presence of moist substrate at the time of a fire event. The conditions necessary for seedling recruitment are unknown though the species are likely to have soil stored seedbank with dormancy broken by fire. Presumably moist conditions are needed for seedling establishment and growth. Unlike the widespread swamp species *Grevillea acanthifolia*, which appears to be a successful coloniser of open sites, and where seedlings appear rapidly in exposed or drying sites (though do not necessarily survive), *Boronia* and *Dillwynia* populations are restricted to much narrower groundwater dependent habitat; loss of groundwater is likely to lead to reduction in their populations.

Because of their occurrence in separate valleys isolated from each other by extensive areas of dry woodland, and often in separate major catchments, genetic diversity in these swamps is often restricted. Dubey and Shine (2010) have highlighted the genetic divergence among swamp populations of *Eulamprus leuraensis*, recommending that most populations be treated as discrete conservation units, with clear implications in the event of extirpation of individual swamp populations. The distinctiveness of individual swamp populations is also supported by Hose's

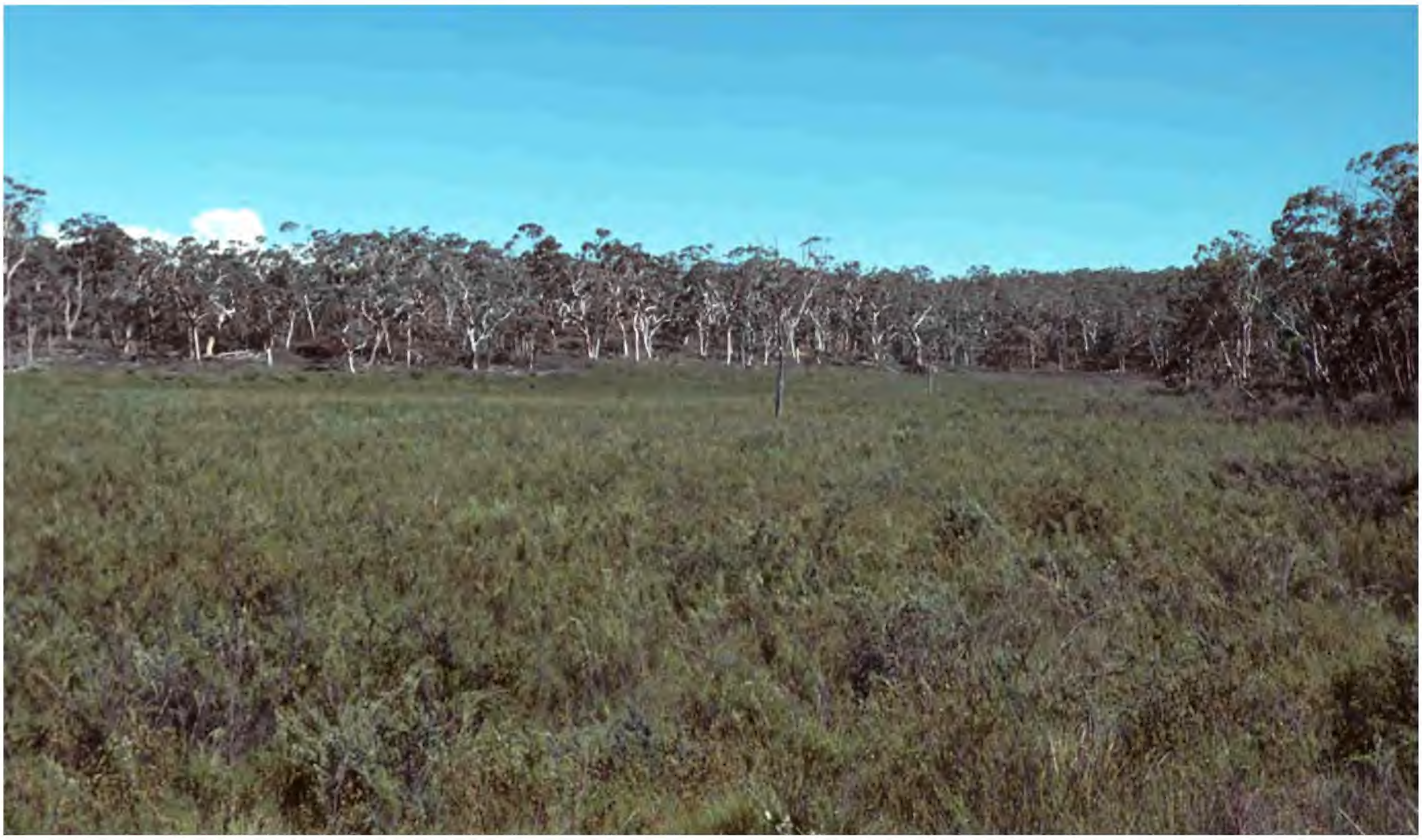


**Fig. 12.** Broad swamp in 1980. There was no sign of any recent fire at this time (photo DHB).

**Table 5. Summary of evidence (both direct and indirect) from various sources that a long-term permanent watertable has indeed been present in the Carne Creek-Clarence swamps.**

| Evidence | Indicative time period |
|---|---|
| Piezometer records for Carne West since 2005 show little fluctuation (Aurecon 2009) | 6 years |
| *Petalura* burrow measurements confirm that regardless of short-term fluctuations associated with rainfall events, and evidence of some adaptive burrow deepening putatively associated with a lowering water table during the drought period, that groundwater levels in these swamps are very stable over long periods. | 5-10 years |
| Vegetation patterns in Broad swamp show little change between 1985-2012 | 30 years |
| Large size of rootstocks of swamp species (e.g. *Gymnoschoenus*, *Boronia deanei*, *Leptospermum grandifolium*, *Baeckea linifolia*) indicates longevity under stable moisture conditions and survival beyond normal two-decade droughts is the norm. These species are unaffected by periodic fires and resprout vigorously. Loss of permanent moisture will lead to death however. | 30-50 years |
| Air photo from 1970s and field experience from that time (DHB) show similar swamp patterns to today | 40 years |
| First recording of *Boronia deanei* in 1906 in habitat and abundance similar to today indicate longevity and consistency of habitat structure. | 100 years |
| Development and maintenance of peat up to 2 m thick indicates long period of high moisture and stability | Very long |
| Records of peat in swamps 12000 years ago | Very long |

(2009) work on stygofauna in swamps on the Woronora Plateau. Genetic diversity among the plant species is also likely to vary, depending on the particular pollination and seed dispersal mechanisms of individual taxa, though there has been little research on this subject despite its importance for guiding longterm conservation management.

### *Longevity of swamp patterns*

The ecology of the native biota, both rare and common species, and characteristics of NPSS indicate that a permanently high watertable is an integral and necessary condition for their survival. Table 5 provides a (necessarily speculative) summary of evidence that a permanently high watertable has indeed been the case over the past centuries. Such evidence comes from various sources. The earliest date for swamps sediments appear to be c.12 000 years ago (Chalson & Martin 2009) and the swamps are likely to have persisted since their formation, though the age of basal sediments at individual core locations may not necessarily reflect the date of initiation of swamp development. In the absence of sediment cores in this study, any interpretation of the observations of contrasting layers of sediment during soil depth probes in different locations within swamps, including dense sands and sandy clay basal layers is hypothetical. Nevertheless, based on research from other sandstone-based swamp systems within the Sydney region (e.g. Woronora Plateau; Young 1982, 1986a, 1986b) it may be presumed that contrasting layers of dense sands and sandy clays interspersed among peat or other organic-rich layers are the result of depositional events associated with rainfall events, most likely following fire and/or drought. Young, and Tomkins & Humphreys (2006) considered that the Woronora swamps were characterised by cycles of sedimentation (mire development) and erosion that may confound interpretation of the oldest sediment dates. Similar episodic degradation and aggradation cycles associated with climate and fire are likely in the mires developed on sandstones in the Blue Mountains.

Notes associated with the collection of *Boronia deanei* in 1906 suggest the swamps were similar to today, while airphotos from the 1960s, and our fieldwork in the 1970s, indicate similar conditions, though with many less disturbed swamps and no evidence of exotic weed species. Swamps visited in the 1970s were moist underfoot and there was invariably water running out at the nick-point discharges visited. An important indicator of temporal vegetation change, individual species longevities, is difficult to determine for species with long-term regeneration structures such as lignotubers, but in the absence of any other leads is probably the only potentially useful measure.

### *Increasing threats to swamps*

With the exception of the construction of the Newnes Valley railway in 1906–07 (which incidentally lead to the discovery of *Boronia deanei*), NPSS survived virtually undisturbed up to the 1970s when major eucalypt forest areas were cleared and planted with exotic *Pinus radiata*. Swamps associated with pine-dominated catchments may now have a major *Leptospermum* component, possibly due to less water runoff, or have increased shading from mature pines and invasion by pine wildings.

Increased demand for electricity and coal in the 1980s lead to proposals for a power station near Birds Rock (relocated to Mount Piper), and the subsequent approval of a major coalmine and washery near the same site, that would have destroyed the main Carne Creek swamps with infrastructure and coal waste dumps. These did not go ahead; instead since the 1990s coalmining using increasingly wider longwall mining technologies have pushed under the plateau from the edges. Though this has reduced the direct impacts of infrastructure on surface vegetation there have still been

**Table 6. Plant species essentially restricted to the highest elevation plateau (>1100 m) of Newnes Plateau, i.e. Clarence to Bungleboori, with conservation status and notes on any disjunct occurrences elsewhere.**

| Species | Cons status | Occurrence on Newnes Plateau | Occurrence elsewhere |
|---|---|---|---|
| *Persoonia hindii* | TSC | WL and heath, >1100 m | Newnes Plateau endemic |
| *Leptospermum blakelyi* | | heath, Clarence, >1100 m | Newnes Plateau endemic |
| *Eucalyptus gregsoniana* | 3RCa | Mallee heath, Clarence, >1100 m | Southern Tablelands, Wadbilliga |
| *Olearia quercifolia* | 3RC- | wet places, >1000 m | confined to Bl Mtns, wet places |
| *Boronia deanei subsp. deanei* | | NPSS, >1100 m | Kanangra-Boyd swamps |
| *Veronica blakelyi* | | WL, Clarence | Nullo Mtn, Mt Horrible |
| *Dillwynia stipulifera* | 3RCa | NPSS, >1100 m | Budawangs |
| *Celmisia longifolia* | | NPSS | Kanangra-Boyd swamps, Southern Tablelands, Kosciuszko, >900 m |
| *Scaevola hookeri* | | NPSS | Blue Mountains Sedge Swamps, disjunct occurrences at high elevations south from Ebor |
| *Isopogon prostratus* | | WL, heath >1100 m (Benson & von Richter 2010) | disjunct occurrences on Southern Tablelands |
| *Hakea microcarpa* | | high elevation swamps, 1130 m | widespread on Tablelands, WL and heathy swamps |
| *Velleia montana* | | NPSS, 1050 m | higher altitudes on Tablelands |

major impacts from excess mine water discharges pumped into the swamps, as well as a plethora of surface roads allowing more access to the area. There are also increasing impacts associated with subsidence, as longwall panels as wide as 310 m have been used. However, with an increased number of direct impacts, together with indirect impacts affecting swamp processes, subsidence and climate change are likely to have major impacts on NPSS in the future.

Changes in groundwater regime will potentially impact the biota of Groundwater Dependent Ecosystems at species and community level. This will be caused by changes to critical habitat attributes, either variably, or (potentially) across threshold levels (Clifton & Evans 2001). Where groundwater levels are lowered, even seasonally, effects may include changes in the wetland vegetation community composition (Boulton & Brock 1999; Breeuwer *et al.* 2009; Wheeler 1999). With longer term and/or persistent lowering of the water table, effects may include succession from swamps to drier heath, sedgeland, grassland or forest communities, extirpation of groundwater dependent species, changes in groundwater quality and soil chemistry (Wheeler 1999) and degradation of peat (Shearer 1997) and peatlands (Moore 2002; Whittington & Price 2006).

In particular, according to NSW Scientific Committee (2005), subsidence of the land surface and associated fracturing of bedrock occurs after longwall coalmining, and this may change the hydrology of catchments and swamps they contain (Krogh 2007). Recent mining related disturbance at East Wolgan has led to loss of stream flow from the swamp; long-term effects are unknown, though there is already death of permanent moisture dependent species such as *Gleichenia* and degradation of the peaty swamp soil (Aurecon 2009, Goldney et al 2010). These effects are likely to be long-term as long as drainage loss continues and oxidation of peat destroys its water holding capacity, allowing woodland plant species to replace the swamp species.

Local disturbance and scouring caused by contaminated mine water discharges has caused erosive channelling, mortality of swamp flora and invasion of exotic weeds such as wind/water dispersed herbs *Cirsium vulgare* and *Sonchus oleraceus* into pristine creek-lines. In contrast, swamp vegetation has recovered well from heavy rain scour reported from Woronora (Tomkins & Humphreys 2006) except for Flatrock Swamp, Swamp 18 and 19, all affected by longwall mining.

Potential impacts associated with a lowering of the water table include weed invasion and increased fire risk (DECC 2005; Keith *et al.* 2006; Kodela *et al.* 2001), and woody weed invasion of swamps by exotic pines, blackberries and other species across the plateau has been documented recently (Henson 2010). Where drying of organic-rich, peaty swamp substrates occurs, fire effects may include burning of

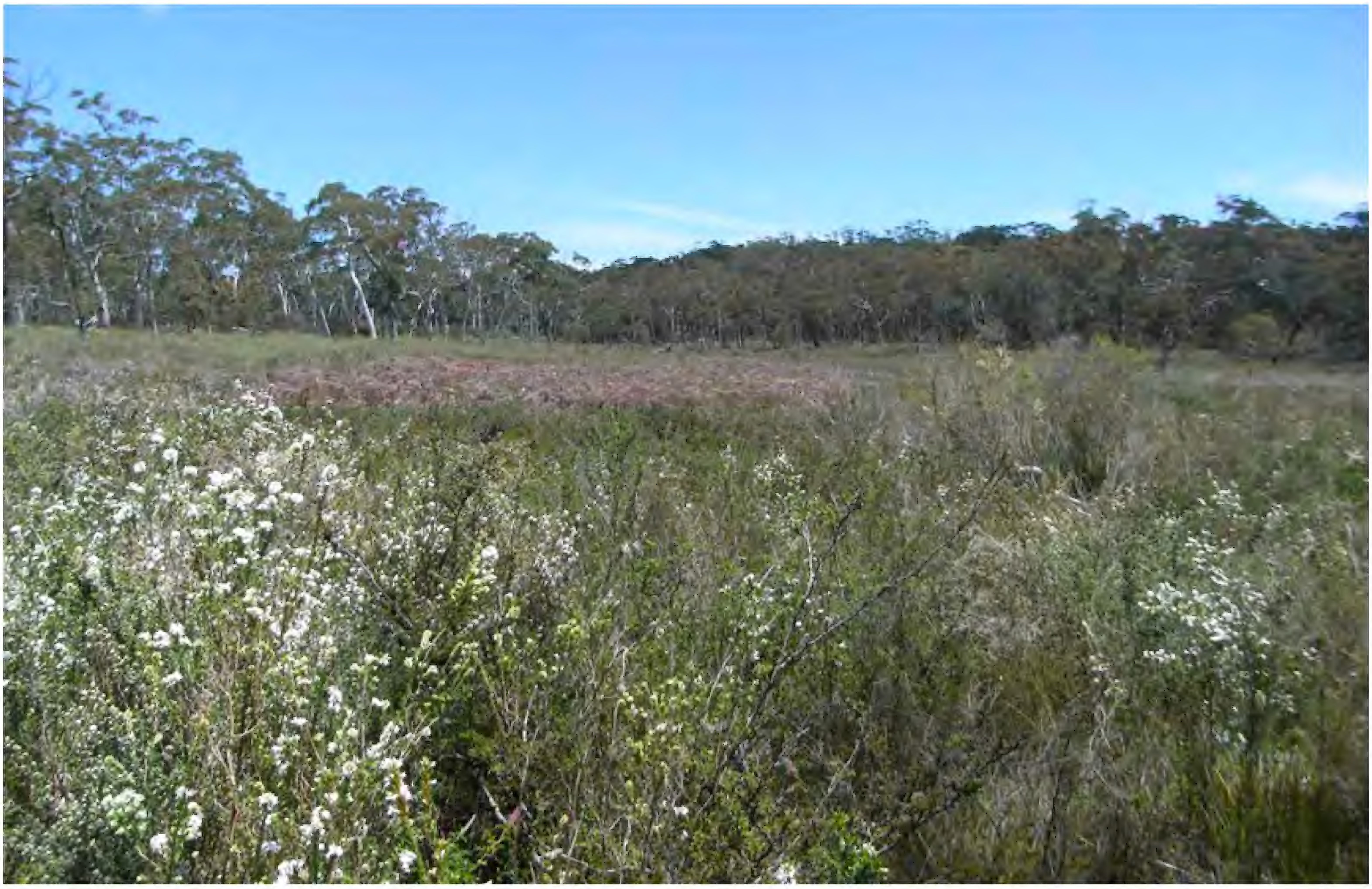


**Fig. 13.** Pink patch of flowering *Boronia deanei* in Broad Swamp in November 2008. (photo L. von Richter).

the organic soil component and soil seed-banks. This has the potential to leave sterilised and (often) hydrophobic sandy or peaty soils, with an increased risk of erosion, in turn leading to channelisation and further lowering of shallow water tables (e.g. Young & Wray 2000). Fire induced changes may also include changes in water quality and loss of biodiversity (e.g. Horwitz & Sommer 2005). Drying related oxidisation and/or combustion of the organic component of these peatlands leads to their shrinkage. Degradation of the hydrological function of these peatland ecosystems may also occur (DECC 2005; Keith *et al.* 2006).

Fire is considered one of the main threats to Australian peatlands (Pemberton 2005). A more intense fire regime may cause unsustainable loss of peatland soils, as in peatlands in southwestern Australia (Horwitz *et al.* 1999; Horwitz & Smith 2005; Semeniuk & Semeniuk 2005) and Tasmania (Bridle *et al.* 2003; Kirkpatrick & Dickinson 1984; Whinam 1995; Whinam *et al.* 2001). Extensive fire effects in *Sphagnum* peatland communities have also been reported in NSW (Hope *et al.* 2005; Threatened Species Scientific Committee 2009; Walsh & McDougall 2004) and Victoria (Coates *et al.* 2006; Taranto *et al.* 2004; Walsh & McDougall 2004). Fire effects are exacerbated where groundwater levels are lowered due to drought or anthropogenic influences (e.g. climate change, groundwater extraction, long wall coal mining) and by more intense fire regimes, for example, as reported also in New Zealand peatlands and bogs (Clarkson 1997; Johnson 2001; Timmins 1992). An increase in periods where peatland soils are bare following fire events (or in response to drought) will also contribute to increased rates of peatland photodegradation and loss of organic matter (Rutledge *et al.* 2010). Lowering of the groundwater table will compound these effects.

Destruction of peat substrates as a result of fire has been reported in BMSS (Keith 1996; Stricker & Wall 1995) and the upland swamps of the Woronora Plateau (Keith *et al.* 2006; Young 1982, Krogh 2007). The temporal and spatial scales, and the intensity at which these fire disturbance events occur in particular swamp types are, however, critical to whether fire regimes result in long-term loss of organic terrains at a rate that exceeds net accumulation of organic matter, or exceeds fire regime thresholds for swamp plant (e.g. *Sphagnum* spp., obligate seeders) and animal species (e.g. *Rattus lutreolus*) (Keith 1996; Keith *et al.* 2002; Morrison 2002; Morrison *et al.* 1995; Watson 2006a, b). Fire impacts are directly correlated to swamp water levels and surface wetness (e.g. Horwitz & Smith 2005; Horwitz & Sommer 2005).

Reduced groundwater availability, particularly combined with a more intense fire regime and/or a hotter and drier climate, will result in long-term degradation, and contraction of these mire ecosystems. The result will be reduced spatio-temporal distribution of suitable breeding habitat for *Petalura gigantea* and will also threaten the persistence of other groundwater dependent species (e.g. *Boronia deanei*, *Eulamprus leuraensis*, *Euastacus australasiensis*). Maintenance of a suitable hydrological regime and groundwater levels will be fundamental to the persistence of these mire ecosystems and their groundwater dependent species, but there are considerable gaps in our knowledge of the ecology of these species, particularly in relation to groundwater hydrology and the nexus between hydrology and fire. With the likelihood of significant impacts and considerable uncertainty associated with climate change projections, the precautionary principle should underpin conservation management of these mire ecosystems.

### *Connecting important landscape elements of the Newnes Plateau*

Perusal of the topography shows that most of the typical groundwater dependent swamps are located on or just below the 1100 m contour, and that this level also applies to Kangaroo Creek Lower, and Narrow and East Wolgan swamps (see Table 1). It is likely that the 1100 m zone relates more or less to the perched unconfined aquifer supplying water to the main groundwater dependent swamps, particularly those in the Carne, Wolgan, Bungleboori, Budgary and Rocky Creek catchments. The western dry swamps (Sunnyside West, West Wolgan and Kangaroo Creek-upper) are located on the Plateau at a higher elevation; their *Leptospermum*–dominated vegetation and shallower less peaty substrate is consistent with the view that they are more rainfall dependent than groundwater dependent. This interpretation helps clarify the position of the somewhat anomalous (now dry) Junction Swamp, which previously, before drying, had permanent moisture, areas of *Sphagnum* moss (not a characteristic species of the main NPSS), and confirmed records of *Eulamprus,*; drying is likely to be a result of the impacts of mining subsidence (Goldney *et al.* 2010). At 1155 m elevation Junction Swamp, the highest elevation swamp, should be a high level dry western swamp, but its small catchment (30 ha), perched aquifer, odd, relatively steep north-eastern aspect, topographic position at the headwater of the upper Wolgan River, and the relatively small area of land at this elevation, make it a unique swamp.

As well as the swamp systems, the Newnes Plateau has particular geodiversity features that add to its scientific values. Below the swamps, at the termination of the adjacent ridges, there are the geologically distinctive and unique sandstone pagoda formations (generally occupying the 800–1050 elevation zone), resulting from millennia of iron-water transport and re-deposition (Washington & Wray 2011). As well, the relict sand dunes described by Hesse (2003) provide a strong indication of climatic conditions at the height of the Last Glacial Maximum (c. 20 000 years ago).

Our fieldwork for the swamps also drew our attention to restricted high elevation vegetation in their catchments. Above the 1100 m contour (the general upper level of the swamps), the Plateau surface rises to nearly 1200 m (e.g. 1190 m on the catchment divide between Marrangaroo, Farmers and Bungleboori creeks; 1180 m at Bald Trig and 1181m at Birds Rock). This 1100–1200 m cap includes a range of vegetation, primarily broadly mapped as Newnes Plateau Woodland map unit 10f (Benson & Keith 1990), but including areas of forest of *Eucalyptus dalrympleana*, woodland of *Eucalyptus dives*, *Eucalyptus radiata*, *Eucalyptus pauciflora* and *Eucalyptus mannifera*, and areas of heath with *Allocasuarina nana*. This area also includes the dry swamps (e.g. West Wolgan, Sunnyside West) and the anomalous Junction Swamp (discussed above). The pattern of occurrence of these vegetation types is substrate-controlled (Wilkinson & Humphreys 2006, Wilkinson et al 2005), which explains the occurrence of heath on relatively sheltered areas below woodland, rather than on exposed sites as around Katoomba or Blackheath. The nature of the friable sandstone (Triassic Narrabeen Group – Banks Wall Sandstone) leads to deep well-drained soils (Pecover 1984, King 1993), which presumably allow easy entry for water movement into aquifers supporting the swamps, but make it highly sought after for sand mining. The high level vegetation (given its relatively small overall area) is important habitat for a large number of rare plants, many with disjunct connections with other high-level montane sites, particularly on the Southern Tablelands (See Table 6). Heath includes *Eucalyptus gregsoniana*, and woodland includes the locally endemic Endangered *Persoonia hindii* (confined to 1100–1200 m), *Isopogon prostratus* (only above 1100 m) and *Acacia meiantha* (1100 m). Forest includes *Veronica* (*Derwentia) blakelyi*. It is tempting to speculate that some of these species occurrences (and some of the prostrate species on the Plateau) are indicative of the prior flora of the site in colder drier conditions, during and following the Last Glacial Maximum, and subsequently invaded by taller growing eucalypts and shrubs. This timing (post LGM) is concurrent with development of the swamps of the Plateau. Such speculation provides testable hypotheses (e.g. see recent genetic studies on *Telopea* (Rossetto *et al.* 2011) and *Lomatia* (M.Rossetto pers comm. 2011) which include Newnes Plateau as a study site). Scientists need to draw attention to this scientifically important high elevation part of the Plateau, none of which is in the nearby national parks, and which is currently faced with such an array of serious threats. In a recent publication, Laurance *et al.* (2011) identify the top ten Australian ecosystems vulnerable to tipping points, in which modest environmental changes can cause disproportionately large changes in ecosystem properties. Elevationally restricted montane ecosystems are listed as the most vulnerable.

## Conclusion

Our Newnes Plateau Shrub Swamp studies show a closely-related group of swamps with extensive areas of gently sloping peatlands with subsurface topography determining local peat depth. While there is evidence that a group of the highest elevation swamps on the western side of the Plateau are more dependent on rainwater, the majority of swamps and those in the Carne Creek catchment, and to its east and south to Clarence in particular, have permanently high water tables maintained by groundwater, and are associated with the concurrence of a number of threatened groundwater dependent biota restricted to these sites. This association makes them highly susceptible to threats of loss of groundwater, the major one being the impact of subsidence caused by longwall mining; though other impacts may come from changes to hydrology as a result of damming, mine waste water discharge, increased moisture competition from pine plantations, and climate change. Our view is that if groundwater hydrology is impacted by activities such as longwall mining and associated subsidence, potential significant ecological damage is unlikely to be avoided or mitigated. Where provisions of the EPBC and TSC Acts apply to groundwater dependent swamps and biota, mining under swamps needs to be avoided.

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## References

Agnew A. D. Q., Rapson G. L. Sykes, M. T.& Wilson, J.B. (1993) The functional ecology of *Empodisma minus* (Hook, f.) Johnson & Cutler in New Zealand ombrotrophic mires. *New Phytologist* 124**,** 703–710.

Aurecon (2009). *Newnes Plateau Shrub Swamp Management Plan – Investigation of Irregular Surface Movement within East Wolgan Swamp*. Centennial Coal. 26 June 2009. Report Reference: 7049–010-Rev 3.

Australian Railway Historical Society. (1979) *The Wolgan Valley Railway – its construction, incorporating The Wolgan Valley Railway* by Henry Deane, read before the Sydney University Engineering Society, Sept 21 1910. (Australian Railway Historical Society NSW Division: Sydney).

Baird I.R.C. (2012) The wetland habitats, biogeography and population dynamics of *Petalura gigantea* (Odonata: Petaluridae) in the Blue Mountains of New South Wales. PhD thesis, University of Western Sydney.

Belbin, L. (2004) *PATN Pattern analysis package*. CSIRO Division of Wildlife Ecology: Canberra.

Benson D. H .(1981) Flora Report. Appendix A Birds Rock Colliery Environmental Impact Statement. January 1981. Birds Rock Colliery Pty. Ltd.

Benson D. H. & Keith D. A. (1990) Natural vegetation of the Wallerawang 1:100,000 map sheet. *Cunninghamia* 2, 305–35.

Benson D. H. & von Richter L. (2010) Recent ecological observations on growth rates and seed production in *Isopogon prostratus* (Proteaceae), a little-known prostrate shrub from south-eastern NSW and Victoria. *Cunninghamia* 11, 283–6.

Bish S. (1999) Hydrogeological Assessment for Coxs River Catchment, Sydney-South Coast Region. NSW Department of Land and Water Conservation, Sydney.

Boulton A. J. & Brock M. A. (1999) *Australian Freshwater Ecology: Processes and Management*. Gleneagles Publishing, Adelaide.

Breeuwer A., Robroek B. J. M., Limpens J., Heijmans M. M. P. D., Schouten M. G. C. & Berendse F. (2009) Decreased summer water table depth affects peatland vegetation. *Basic and Applied Ecology* 10, 330–9.

Bridle K. L., Cullen P. & Russell M. (2003) *Peatland Hydrology, Fire Management and Holocene Fire Regimes in Southwest Tasmanian Blanket Bogs. Nature Conservation Report No. 03/07*. Nature Conservation Branch, Department of Primary Industries, Water and Environment, Hobart.

Brown M. J., Crowden R. K. & Jarman S. J. (1982) Vegetation of an alkaline pan-acidic peat mosaic in the Hardwood River Valley, Tasmania. *Austral Ecology* 7, 3–12.

Buchanan R. A. (1980) The Lambert Peninsular, Ku-ring-gai Chase National Park. Physiography and the distribution of podzols, shrublands and swamps, with details of the swamp vegetation and sediments. *Proceedings of the Linnean Society of NSW* 104, 73–94.

Butterfield J. & Coulson J. C. (1983) The carabid communities on peat and upland grasslands in northern England. *Holarctic Ecology* 6, 163–74.

Campbell N. (2007) Clarence Colliery Environmental Monitoring Program. [Accessed September 23rd 2009]. Available from http://www.centennialcoal.com.au/index.php?option=com_content&view=article&id=40:clarence&catid=14:operations-a-community&Itemid=48

Centennial Angus Place. (2006) Angus Place Colliery Subsidence Management Plan: Newnes Plateau Shrub Swamp Management Plan. [Accessed September 23rd 2009]. Available from http://www.centennialcoal.com.au/index.php?option=com_content&view=article&id=35&Itemid=43

Centennial Coal. (2005) Angus Place Colliery Longwalls 930–980 Subsidence Management Plan Application. Centennial Angus Place.

Centennial Coal 2009. Springvale Colliery Subsidence Management Status Report. Four Monthly Update. 7th March 2009.

Chalson, J. M. & Martin, H.A. (2009) A Holocene history of the vegetation of the Blue Mountains, New South Wales. *Proceedings of the Linnean Society of NSW* 130, 77–109.

Clarke K.R. and Warwick R.M. 2001. *Change in Marine Communities: An Approach to Statistical Analysis and Interpretation*. 2nd Edition. PRIMER-E Ltd. Plymouth Marine Laboratory, UK.

Clarke P. J. & Martin R. H. (1999) *Sphagnum* peatlands of Kosciuszko National Park in relation to altitude, time and distance. *Australian Journal of Botany* 47, 519–36.

Clarkson B. R. (1997) Vegetation recovery following fire in two Waikato peatlands at Whangamarino and Moanatuatua, New Zealand. *New Zealand Journal of Botany* 35, 167–79.

Clifton C. & Evans R. (2001) *Environmental Water Requirements of Groundwater Dependent Ecosystems, Environmental Flows Initiative Technical Report Number 2*. Commonwealth of Australia, Canberra.

Coates F., Sutter G. & Mavromihalis J. (2006) Regeneration of treeless subalpine vegetation after recurrerent fires at Mt Buffalo National Park. Technical Series Report No. 160. Arthur Rylah Institute for Environmental Research, Melbourne.

Corbet P. S. (2004) *Dragonflies. Behaviour and Ecology of Odonata*. Revised edition. Cornell University Press, Ithaca, NY.

Creaser E. P. (1931) Some cohabitants of burrowing crayfish. *Ecology* 12, 243–4.

CSIRO. (2004) Interpretation of hydrological data at Springvale Colliery. Exploration and mining report P2004/62. CSIRO Exploration & Mining, Kenmore, Qld.

Davis J. A., Froend R. H., Hamilton D. P., Horwitz P., McComb A. J. & Oldham C. E. (2001) *Environmental Water Requirements to Maintain Wetlands of National and International Importance, Environmental Flows Initiative Technical Report Number 1*. Commonwealth of Australia, Canberra.

DEC (2006) The Vegetation of the Western Blue Mountains including the Capertee, Coxs, Jenolan & Gurnang areas. Volume 2: Vegetation community profiles. Newnes Plateau shrub swamp. NSW Dept of Environment and Conservation, Hurstville.

DECCW (2010a) *NSW Wetlands Policy*. NSW Dept of Environment, Climate Change & Water, Hurstville.

DECCW (2010b) Review of Piezometer Monitoring Data in Newnes Plateau Shrub Swamps and their relationship with Underground Mining in the Western Coalfield. NSW Department of Environment, Climate Change and Water. January 2010.

DEH (2005) *Nationally threatened Species and Ecological communities: Temperate Highland Peat Swamps on Sandstone*, Australian Govt Dept of Environment and Heritage.

DLWC. (1999a) Blue Mountains – Richmond Interim Groundwater Management Plan. Department of Land and Water Conservation, Parramatta, NSW.

DLWC. (1999b) Blue Mountains Sandstone Aquifer Current Groundwater Management Practices and Issues. Department of Land and Water Conservation, Parramatta, NSW.

DLWC. (1999c) Blue Mountains Sandstone Aquifer Status Report. Department of Land and Water Conservation, Parramatta, NSW.

Dubey S. & Shine R. (2010) Restricted dispersal and genetic diversity in populations of an endangered montane lizard (*Eulamprus leuraensis*, Scincidae). *Molecular Ecology* 19, 886–97.

Eamus D. & Froend R. (2006) Groundwater-dependent ecosystems: the where, what and why of GDEs. *Australian Journal of Botany* 54, 91–6.

Enforceable undertaking (2011) – Enforceable Undertaking - undertaking to the Minister for Sustainability, Environment, Water, Population and Communities given for the purpose of section 486DA by Springvale Coal Pry Limited and Centennial Angus Place Pty Limited (PDF - 47KB) http://www.environment.gov.au/epbc/compliance/pubs/enforceable-undertaking-centennial.pdf

Fletcher A. T. & Erskine P. D. (2012) Mapping of a rare plant species (*Boronia deanei*) using hyper-resolution remote sensing and concurrent ground observation. *Ecological Mangement and Restoration* 13, 195–198.

Gilbert J., Danielopol D. L. & Stanford J. A. (1994a) *Groundwater Ecology*. Academic Press, San Diego.

Gilbert J., Stanford J. A., Dole-Olivier M.-J. & Ward J. V. (1994b) Basic attributes of groundwater ecosystems and prospects for research. In: *Groundwater Ecology* (eds J. Gilbert, D. L. Danielopol and J. A. Stanford) pp. 10–3. Academic Press, San Diego.

Goldney D., Mactaggart B. & Merrick N. (2010) Determining whether or not a significant impact has occurred on Temperate Highland Peat Swamps on Sandstone within the Angus Place Colliery Lease on the Newnes Plateau. Prepared for

Department of the Environment, Water, Heritage and the Arts, January 2010.

Gore A. J. P. (1983) *Ecosystems of the World 4A. Mires: Swamp, Bog, Fen and Moor*. Elsevier, Amsterdam.

Greenslade P. & Smith D. (1999) The epigaeic arthropod fauna of buttongrass moorland in Tasmanian Wilderness World Heritage Area. In: *The Other 99%: the Conservation and Biodiversity of Invertebrates* (eds W. F. Ponder and D. Lunney) pp. 90–4. Transactions of the Royal Zoological Society of New South Wales, Mosman, NSW.

Growns I. O. & Marsden T. (1998) Altitude separation and pollution tolerance in the freshwater crayfish *Euastacus spinifer* and *E. australasiensis* (Decapoda:Parastacidae) in coastal flowing streams of the Blue Mountains, New South Wales. *Proceedings of the Linnean Society of NSW* 120, 139–45.

Growns I. O. & Richardson A. M. M. (1988) Diet and burrowing habits of the freshwater crayfish, *Parastacoides tasmanicus tasmanicus* Clark (Decapoda : Parastacidae). *Marine and Freshwater Research* 39, 525–34.

Hahn H. J. (2000) Studies on classifying of undisturbed spring in southwestern Germany by macrobenthic communities. *Limnologica – Ecology and Management of Inland Waters* 30, 247–59.

Hájek M., Horsák M., Hájková P. & Díte D. (2006) Habitat diversity of central European fens in relation to environmental gradients and an effort to standardise fen terminology in ecological studies. *Perspectives in Plant Ecology, Evolution and Systematics* 8, 97–114.

Hatton T. & Evans R. (1998) *Dependence of Ecosystems on Groundwater and its Significance to Australia*. LWRRDC Occasional Paper No. 12/98. Land and Water Resources Research & Development Corporation, Canberra.

Hesse P. P., Humphreys G. S., Selkirk P. M., Adamson D. A., Gore D. B., Nobes D. C.,Price D. M., Schwenninger J. -L., Smith B., Tulau M. & Hemmings F. (2003) Late Quaternary aeolian dunes on the presently humid Blue Mountains, Eastern Australia. *Quaternary International* 108, 13–32.

Hoffsten P.-O. & Malmqvist B. (2000) The macroinvertebrate fauna and hydrogeology of springs in central Sweden. *Hydrobiologia* 436, 91–104.

Holland W. N., Benson D. H. & McRae R. H. D. (1992a) Spatial and temporal variation in a perched headwater valley in the Blue Mountains: geology, geomorphology, vegetation, soils and hydrology. *Proceedings of the Linnean Society of NSW* 113, 271–95.

Holland W. N., Benson D. H. & McRae R. H. D. (1992b) Spatial and temporal variation in a perched headwater valley in the Blue Mountains: solar radiation and temperature. *Proceedings of the Linnean Society of NSW* 113, 297–309.

Hope G., Whinam J. & Good R. (2005) Methods and preliminary results of post-fire experimental trials of restoration techniques in the peatlands of Namadgi (ACT) and Kosciuszko National Parks (NSW). *Ecological Management & Restoration* 6, 214–7.

Horwitz P. & Knott B. (1983) The burrowing habit of the Koonac *Cherax plebejus* (Decapoda: Parastacidae). *West Australian Naturalist* 15, 113–7.

Horwitz P., Pemberton M. & Ryder D. (1999) Catastrophic loss of organic carbon from a management fire in a peatland in southwestern Australia. In: *Wetlands for the Future* (eds A. J. McComb and J. A. Davis) pp. 487–501. Gleneagles Publishing, Adelaide, South Australia.

Horwitz P. & Smith R. (2005) Fire and wetland soils and sediments on the Swan Coastal Plain: an introduction. *Journal of the Royal Society of Western Australia* 88, 77–9.

Horwitz P. & Sommer B. (2005) Water quality responses to fire, with particular reference to organic-rich wetlands and the Swan Coastal Plain: a review. *Journal of the Royal Society of Western Australia* 88, 121–8.

Horwitz P. H. J. & Richardson A. M. M. (1986) An ecological classification of the burrows of Australian freshwater crayfish. *Marine and Freshwater Research* 37, 237–42.

Horwitz P. H. J., Richardson A. M. M. & Cramp P. M. (1985) Aspects of the life history of the burrowing crayfish *Engaeus leptorhyncus* at Rattrays Marsh, north-east Tasmania. *Tasmanian Naturalist* 82, 1–5.

Hose G (2009) ‘Stygofauna baseline assessment for Kangaloon borefield investigations – Southern Highlands, NSW. Supplementary report – stygofauna molecular studies.’ Report to Sydney Catchment Authority. Access Macquarie Ltd, North Ryde.

Humphreys W. F. (2008) Rising from down under: developments in subterranean biodiversity in Australia from a groundwater fauna perspective. *Invertebrate Systematics* 22, 85–101.

Irwin J. T., Costanzo J. P. & Lee Jr R. E. (1999) Terrestrial hibernation in the northern cricket frog, *Acris crepitans*. *Canadian Journal of Zoology* 77, 1240–6.

Jabło ska E., Pawlikowski P., Jarzombkowski F., Chormański J., Okruszko T. & Kłosowski S. (2011) Importance of water level dynamics for vegetation patterns in a natural percolation mire (Rospuda fen, NE Poland). *Hydrobiologia* 674, 105–17.

Johnson P. N. (2001) Vegetation recovery after fire on a southern New Zealand peatland. *New Zealand Journal of Botany* 39, 251–67.

Keith D. A. (1996) Fire–driven extinction of plant populations: a synthesis of theory and review of evidence from Australian vegetation. *Proceedings of the Linnean Society of NSW* 116, 37–78.

Keith D. A. (2004) *Ocean Shores to Desert Dunes: the Native Vegetation of New South Wales and the ACT*. Department of Environment and Conservation (NSW), Hurstville.

Keith D. A. & Myerscough P. J. (1993) Floristics and soil relations of upland swamp vegetation near Sydney. *Australian Journal of Ecology* 18, 325–44.

Keith D. A., McGaw L. & Whelan R. J. (2002) Fire regimes in Australian heathlands and their effects on plants and animals. In: *Flammable Australia: the Fire Regimes and Biodiversity of a Continent* (eds R. A. Bradstock, J. E. Williams and A. M. Gill). Cambridge University Press, Cambridge.

Keith D. A., Rodoreda S., Holman L. & Lemmon J. (2006) Monitoring change in upland swamps in Sydney’s water catchments: the roles of fire and rain. Sydney Catchment Authority Special Area Strategic Management Research and Data Program. Project number RD07: Long term responses of upland swamps to fire. Final Report. Department of Environment and Conservation, Hurstville, NSW.

King D. P. (1993) *Soil Landscapes of the Wallerawang 1:100,000 Sheet Report*. Department of Conservation and Land Management, Sydney.

Kirkpatrick J. B. & Bridle K. L. (1998) Environmental relationships of floristic variation in the alpine vegetation of southeastern Australia. *Journal of Vegetation Science* 9, 251–60.

Kirkpatrick J. B. & Dickinson K. J. M. (1984) The impact of fire on Tasmanian alpine vegetation and soils. *Australian Journal of Botany* 32, 613–29.

Kodela P., James T. A. & Hind P. D. (1996) Vegetation and flora of swamps of the Boyd Plateau, Central Tablelands, New South Wales. *Cunninghamia* 4, 525–30.

Kodela P. G., Sainty G. R., Bravo F. J. & James T. A. (2001) Wingecarribee Swamp flora survey and related management issues. Unpublished report to Sydney Catchment Authority, New South Wales.

Krogh, M. 2007. Management of Longwall Coal Mining Impacts in Sydney’s Southern Drinking Water Catchments. *Australasian Journal of Environmental Management*, 14, 155–165.

Lake P. S. (1977) Pholoteros – the faunal assemblage found in crayfish burrows. *Australian Society of Limnology Newsletter* 15, 57–60.

Lake P. S. & Newcombe K. J. (1975) Observations on the ecology of the crayfish *Parastacoides tasmanicus* (Decapoda: Parastacidae) from south-western Tasmania. *Australian Journal of Zoology* 18, 197–214.

Larson D. J. & House N. L. (1990) Insect communities of Newfoundland bog pools with emphasis on the Odonata. *Canadian Entomologist* 122, 469–501.

Laurance W. F., Dell B., Turton S. M., Lawes M. J., Hutley L. B., McCallum H., Dale P., Bird M., Hardy G., Prideaux G., Gawne B., McMahon C. R., Yu R., Hero J. -M., Schwarzkopf L., Krockenberger A., Douglas M., Silvester E., Mahony M., Vella K., Saikia U., Wahren C. -H., Xu Z., Smith B. & Cocklin C. (2011) The 10 Australian ecosystems most vulnerable to tipping points. *Biological Conservation* 144: 1472–80.

LeBreton M. (1996) Habitat and distribution of the Blue Mountains swamp skink (*Eulamprus leuraensis*). B. Zool. (Hons.) thesis. University of New South Wales, Sydney.

Maiden J. H. & Betche E. (1906) Notes from the Botanic Gardens, Sydney No. 12. *Proceedings of the Linnean Society of NSW* 31, 732–42.

Marshall B. (2005) *Groundwater: Lifeblood of the Environment*. Blue Mountains Conservation Society, Wentworth Falls, NSW.

McKibben D. & Smith P. C. (2000) Sandstone hydrogeology of the Sydney region. In: *Sandstone City: Sydney's Dimension Sandstone and other Sandstone Geomaterials: Proceedings of a Symposium held on 7 July 2000* (eds G. H. McNally and B. J. Franklin) pp. 83–97. Geological Society of Australia, Springwood.

Merrick J. R. (1998) *Endemic Crayfishes of the Sydney Region: Distribution, Biology and Management Options*. Macquarie University, North Ryde, NSW.

Mikkola K. & Spitzer K. (1983) Lepidoptera associated with peatlands in central and northern Europe: a synthesis. *Nota Lepidopterologica* 6, 216–29.

Mitsch W. J. & Gosselink J. G. (2007) *Wetlands*. John Wiley & Sons, Hoboken, New Jersey.

Mitsch W. J., Gosselink J. G., Anderson C. J. & Zhang L. (2009) *Wetland Ecosystems*. John Wiley & Sons, Hoboken, New Jersey.

Moore P. D. (1989) The ecology of peat-forming processes: a review. *International Journal of Coal Geology* 12, 89–103.

Moore P. D. (2002) The future of cool temperate bogs. *Environmental Conservation* 29, 3–20.

Moore P. D. & Bellamy D. J. (1974) *Peatlands*. Elek Science, London.

Morgan G. J. (1997) Freshwater crayfish of the genus *Euastacus* Clark (Decapoda: Parastacidae) from New South Wales, with a key to all species of the genus. *Records of the Australian Museum* Supplement 23 (1997), 110 pp.

Morrison D. A. (2002) Effects of fire intensity on plant species composition of sandstone communities in the Sydney region. *Austral Ecology* 27, 433–41.

Morrison D. A., Cary G. J., Pengelly S. M., Ross D. G., Mullins B. J., Thomas C. R. & Anderson T. S. (1995) Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: inter-fire interval and time-since-fire. *Australian Journal of Ecology* 20, 239–47.

Murray B. R., Zeppel J. B., Hose G. C. & Eamus D. (2003) Groundwater-dependent ecosystems in Australia: it's more than just water for rivers. *Ecological Management & Restoration* 4, 110–3.

NPWS. (2001) Blue Mountains Water Skink. Threatened species profile. National Parks & Wildlife Service of NSW, Sydney.

NSW Government. (2002) *The NSW State Groundwater Dependent Ecosystems Policy*. Department of Land and Water Conservation and the State Groundwater Policy Working Group, Sydney.

NSW Scientific Committee. (1998) Giant dragonfly – endangered species listing. NSW Scientific Committee final determination. [Accessed August 13th 2008]. Available from http://www.environment.nsw.gov.au/determinations/GiantDragonflyEndSpListing.htm

NSW Scientific Committee. (2002) Alteration to the natural flow regimes of rivers, streams, floodplains and wetlands. NSW Scientific Committee Key Threatening Process final determination. [Accessed December 10th 2009]. Available from http://www.environment.nsw.gov.au/threatenedspecies/AlterationNaturalFlowKTPListing.htm

NSW Scientific Committee. (2004) Montane Peatlands and Swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions – endangered ecological community listing. NSW Scientific Committee final determination. [Accessed August 13th 2008]. Available from http://www.environment.nsw.gov.au/determinations/MontanePeatlandsEndSpListing.htm

NSW Scientific Committee. (2005) Newnes Plateau Shrub Swamp in the Sydney Basin Bioregion – endangered ecological community listing. NSW Scientific Committee final determination. [Accessed August 13th 2008]. Available from http://www.environment.nsw.gov.au/determinations/NewnesPlateauShrubSwampEndSpListing.htm

NSW Scientific Committee. (2005) Alteration of habitat following subsidence due to longwall mining. NSW Scientific Committee Key Threatening Process final determination. [Accessed May 29th 2005]. Available from http://www.environment.nsw.gov.au/determinations/LongwallMiningKtp.htm

Pecover S. R. (1984) Friable sandstones of the Sydney Basin – a major source of industrial and construction for the Sydney market. *Geological Society of Australia Abstracts* 12, 430–2.

Pemberton M. (2005) Australian peatlands: a brief consideration of their origin, distribution, natural values and threats. *Journal of the Royal Society of Western Australia* 88, 81–9.

Richardson A. M. M. (1983) The effect of the burrows of a crayfish on the respiration of the surrounding soil. *Soil Biology and Biochemistry* 15, 239–42.

Richardson A. M. M. & Horwitz P. H. J. (1988) Habitat partitioning by Australian burrowing crayfish. *Freshwater Crayfish* 7, 91–7.

Richardson A. M. M. & Swain R. (1980) Habitat requirements and distribution of *Engaeus cisternarius* and three subspecies of *Parastacoides tasmanicus* (Decapoda: Parastacidae), burrowing crayfish from an area of south-western Tasmania. *Australian Journal of Marine and Freshwater Research* 31, 475–84.

Richardson A. M. M. & Swain R. (1991) Pattern and persistence in the burrows of two species of the freshwater crayfish, *Parastacoides* (Decapoda: Parastacidae), in southwest Tasmania. *Memoirs of the Queensland Museum* 31, 283.

Richardson A. M. M. & Wong V. (1995) The effect of a burrowing crayfish, *Parastacoides* sp., on the vegetation of Tasmanian wet heathlands. *Freshwater Crayfish* 10, 174–82.

Rossetto M., Thurlby K.A.G., Offord, C.A., Allen, C.B. & Weston, P.H. (2011) The impact of distance and a shifting temperature gradient on genetic connectivity across a heterogeneous landscape. *BMC Evolutionary Biology* 11:126.

Rutledge S., Campbell D. I., Baldocchi D. & Schipper L. A. (2010) Photodegradation leads to increased carbon dioxide losses from terrestrial organic matter. *Global Change Biology* 16, 3065–74.

Semeniuk V. & Semeniuk C. A. (2005) Wetland sediments and soils on the Swan Coastal Plain, southwestern Australia: types, distribution, susceptibility to combustion, and implications for fire management. *Journal of the Royal Society of Western Australia* 88, 91–120.

Shearer J. C. (1997) Natural and anthropogenic influences on peat development in Waikato/Hauraki Plains restiad bogs. *Journal of the Royal Society of New Zealand* 27, 295–313.

Spitzer K. & Danks H. V. (2006) Insect biodiversity of boreal peat bogs. *Annual Review of Entomology* 51, 137–61.

Springvale Coal. (2005) Springvale Colliery Longwalls 411–418 Subsidence Management Plan Application. Springvale Coal.

Springvale Coal. (2008) Springvale Colliery 2008 Annual Environmental Management Report. [Accessed September 23rd 2009]. Available from http://www.centennialcoal.com.au/index.php?option=com_content&view=article&id=35&Itemid=43

Stricker J. S. & Wall C. A. (1995) Wetlands of the Nepean – Hawkesbury Catchment. Sydney Water Corporation, Sydney.

Suter P. J. & Richardson A. M. M. (1977) The biology of two species of *Engaeus* (Decapoda : Parastacidae) in Tasmania. III. Habitat, food, associated fauna and distribution. *Marine and Freshwater Research* 28, 95–103.

Swan G., Shea G. & Sadlier R. (2004) *A Field Guide to Reptiles of New South Wales*. Reed New Holland, Sydney.

Taranto M., Downe J., Coates F. & Oates A. (2004) Recovery of Montane Swamp Complex after bushfires in north-east Victoria 2003. Arthur Rylah Institute for Environmental Research Technical Report Series No. 152. Department of Sustainability and Environment, Heidelberg.

Theischinger G. & Endersby I. (2009) *Identification Guide to the Australian Odonata*. Department of Environment, Climate Change and Water NSW, Hurstville, NSW.

Threatened Species Scientific Committee (TSSC). (2005) Commonwealth Listing Advice on Temperate Highland Peat Swamps on Sandstone. [Accessed October 16th 2009]. Available from http://www.environment.gov.au/biodiversity/threatened/publications/temperate-highland-peat-swamps.html

Threatened Species Scientific Committee. (2009) Alpine *Sphagnum* Bogs and Associated Fens ecological community Listing Advice. [Accessed September 6th 2010]. Available from http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=29&status=Endangered

Tillyard R. J. (1911) Studies in the life-histories of Australian Odonata. 4. Further notes on the life-history of *Petalura gigantea* Leach. *Proceedings of the Linnean Society of NSW* 36, 86–96.

Timmins S. M. (1992) Wetland vegetation recovery after fire: Eweburn Bog, Te Anau, New Zealand. *New Zealand Journal of Botany* 30, 383–99.

Tomkins K.M. & Humphreys G.S. (2006) Technical Report No 2. Upland swamp development and erosion on the Woronora Plateau during the Holocene. Sydney Catchment Authority (SCA).

Trueman J. W. H. (2000) Survey for *Petalura gigantea* Leach (Giant Dragonfly) in New South Wales: 1999–2000 flight season. Unpublished report to NSW National Parks and Wildlife Service.

Turbott E. G. (1949) Discovery of the breeding habits of *Leiopelma hochstetteri* Fitzinger. *Records of the Auckland Institute & Museum* 3, 373–6.

Walsh N. G. & McDougall K. L. (2004) Progress in the recovery of the flora of treeless subalpine vegetation in Kosciusko National Park after the 2003 fires. *Cunninghamia* 8, 439–52.

Washington H. G. & Wray, R. A. L. (2011) The geoheritage and geomorphology of the sandstone pagodas of the north-western Blue Mountains region (NSW). *Proceedings of the Linnean Society of NSW* 132, 131–43.

Watson P. (2006a) *Hotspots Fire Project: Fire and the Vegetation of the Southern Rivers Region*. Nature Conservation Council of NSW and the NSW Government Environmental Trust, Sydney.

Watson P. (2006b) *Hotspots Fire Project: Fire Frequency Guidelines and the Vegetation of the Northern Rivers Region*. Nature Conservation Council of NSW and the NSW Government Environmental Trust, Sydney.

Wheeler B. D. (1999) Water and plants in freshwater wetlands. In: *Eco-hydrology: Plants and Water in Terrestrial and Aquatic Environments* (eds A. J. Baird and R. L. Wilby) pp. 127–80. Routledge, London.

Wheeler B. D. & Proctor M. C. F. (2000) Ecological gradients, subdivisions and terminology of north-west European mires. *Journal of Ecology* 88, 187–203.

Whinam J. (1995) Effects of fire on Tasmanian *Sphagnum* peatlands. In: *Bushfire '95: Presented papers, Australian Bushfire Conference, 27–30 September 1995*. Forestry Tasmania, Parks and Wildlife Service, Tasmanian Fire Service, Hobart, Tasmania.

Whinam J., Barmuta L. A. & Chilcott N. (2001) Floristic descriptions and environmental relationships of Tasmanian *Sphagnum* communities and their conservation management. *Australian Journal of Botany* 49, 673–85.

Whinam J. & Hope G. S. (2005) The peatlands of the Australasian region. In: *Moore: von Sibirien bis Feuerland – Mires: from Siberia to Tierra del Fuego* (ed G. M. Steiner) pp. 397–434. Biologiezentrum der Oberoesterreichischen Landesmuseen Neue Serie 35, Linz.

Whittington P. N. & Price J. S. (2006) The effects of water table draw-down (as a surrogate for climate change) on the hydrology of a fen peatland, Canada. *Hydrological Processes* 20, 3589–600.

Williams D. D. & Danks H. V. (1991) Arthropods of springs: Introduction. *Memoirs of the Entomological Society of Canada* 155, 3–5.

Wilkinson M. T. & Humphreys G. S. (2006) Slope aspect, slope length and slope inclination controls of shallow soils vegetated by sclerophyllous heath—links to long-term landscape evolution. *Geomorphology* 76, 347–62.

Wilkinson M. T., Chappell J., Humphreys G. S., Fifield K., Smith B. & Hesse P. (2005) Soil production in heath and forest, Blue Mountains, Australia: influence of lithology and palaeoclimate. *Earth Surface Processes and Landforms* 30, 923–34.

Yabe K. & Onimaru K. (1997) Key variables controlling the vegetation of a cool-temperate mire in northern Japan. *Journal of Vegetation Science* 8, 29–36.

Young A. R. M. (1980) Swampy treeless dells on the Nepean Ramp, N.S.W. In: *Newcastle (16th) Conference of the Institute of Australian Geographers* pp. 437–41. Department of Geography, University of Newcastle, Newcastle.

Young A. R. M. (1982) Upland swamps (dells) on the Woronora Plateau. PhD thesis. University of Wollongong.

Young A. R. M. (1986a) The geomorphic development of dells (upland swamps) on the Woronora Plateau, N.S.W., Australia. *Zeitschrift fur Geomorphologie* 30, 317–27.

Young A. R. M. (1986b) Quaternary sedimentation on the Woronora Plateau and its implications for climatic change. *Australian Geographer* 17, 1 – 5.

Young R. W. & Wray R. A. L. (2000) The geomorphology of sandstones in the Sydney region. In: *Sandstone City: Sydney's Dimension Sandstone and other Sandstone Geomaterials: Proceedings of a Symposium held on 7 July 2000* (eds G. H. McNally and B. J. Franklin). Geological Society of Australia, Springwood.

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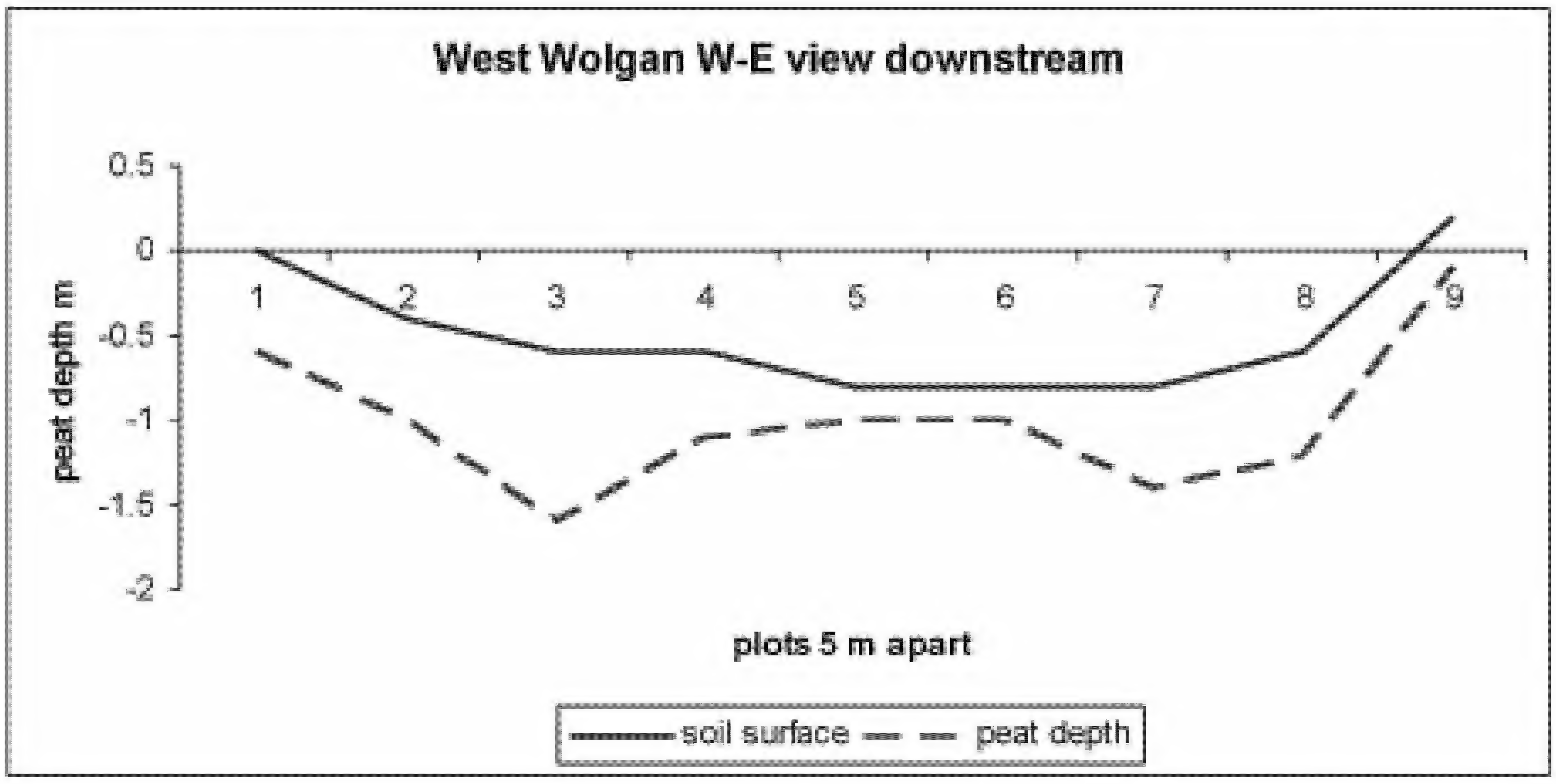
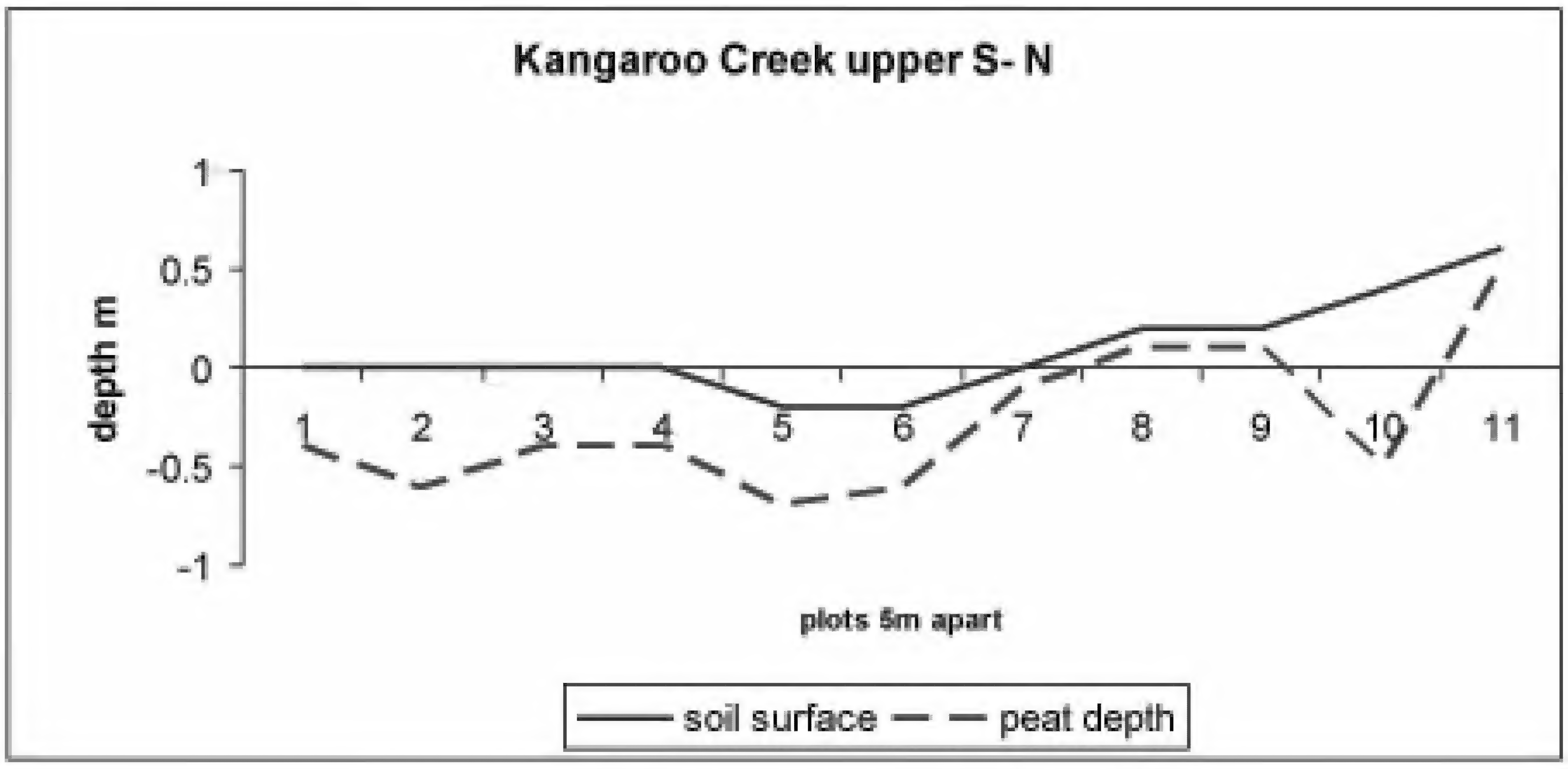
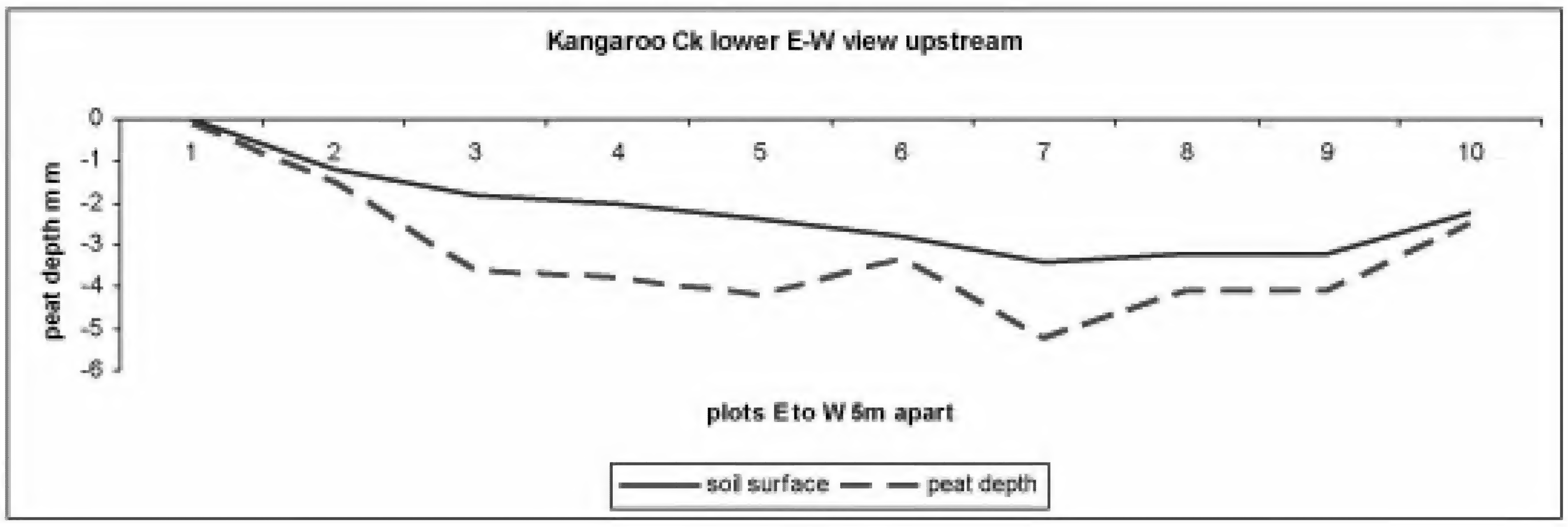
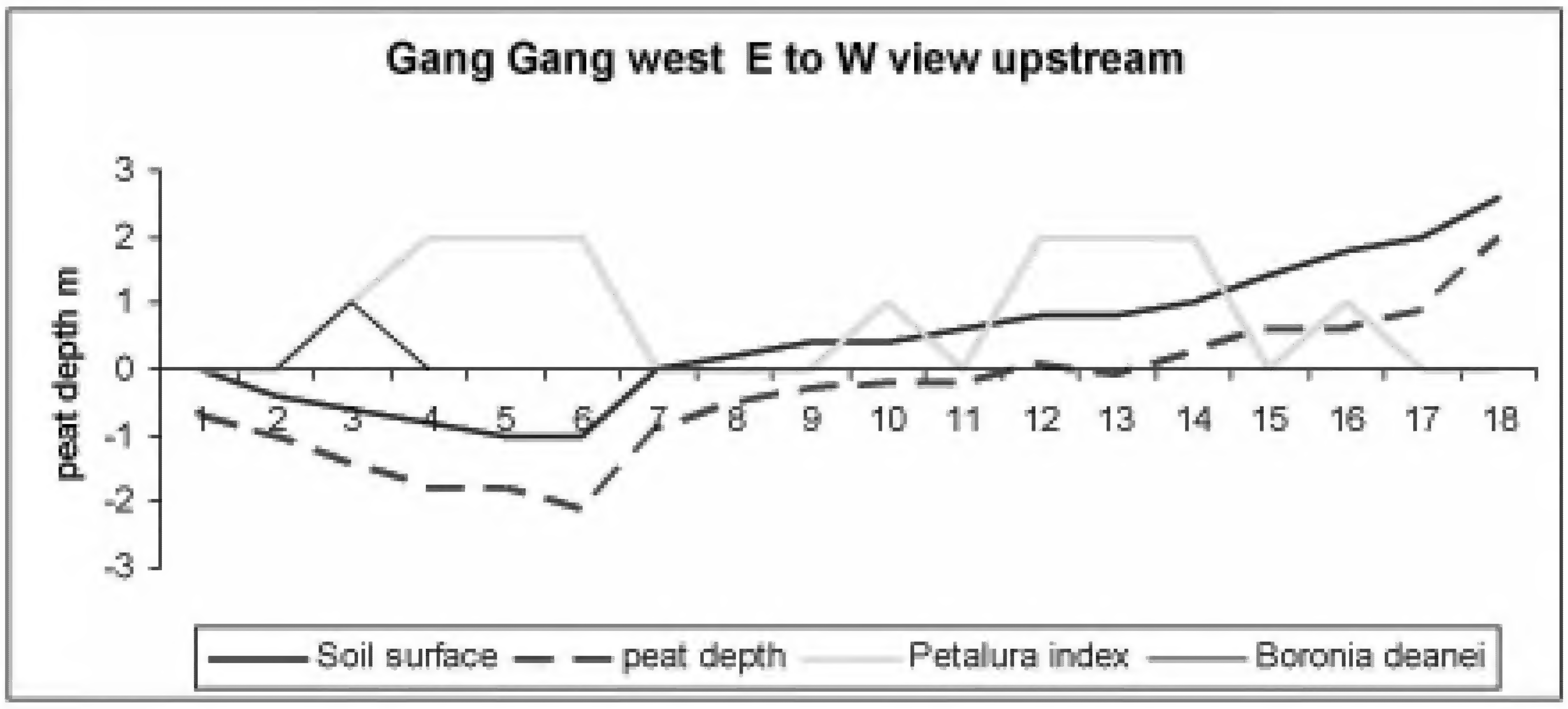
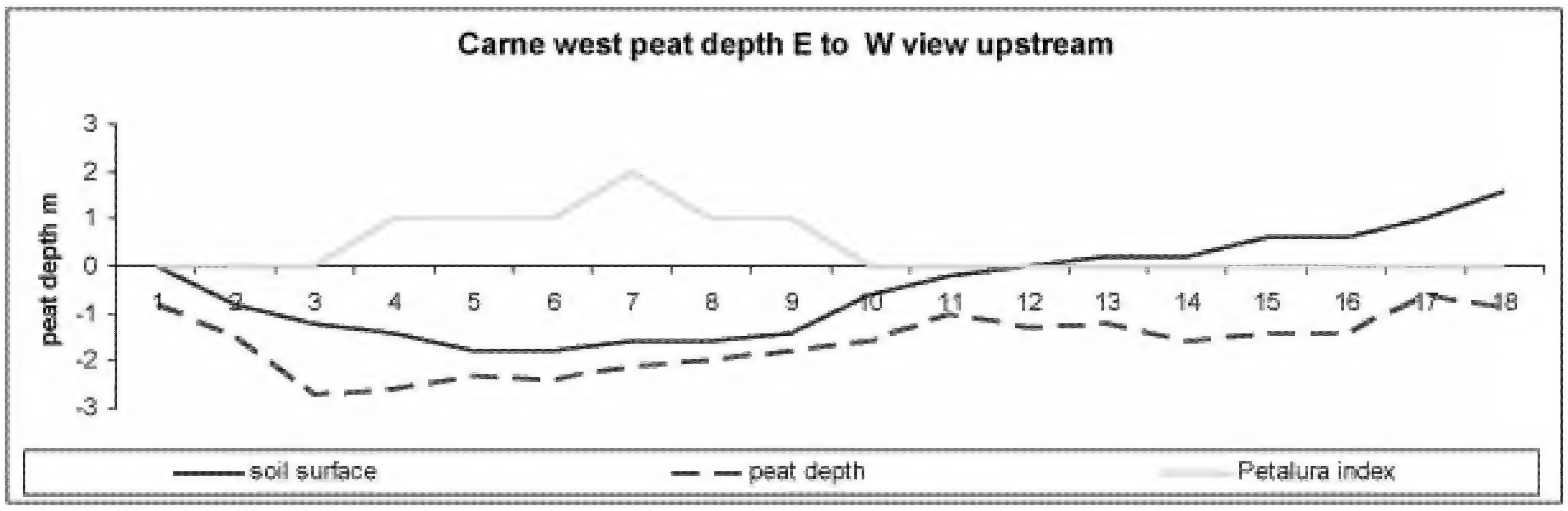
## APPENDIX 1 Cross sections of swamps ordered by decreasing elevation, compiled from 5m interval transect points showing surface topography, peat depth (m) and surface water (cm), *Petalura* index (1–3) and *Boronia deanei* presence where recorded (1).

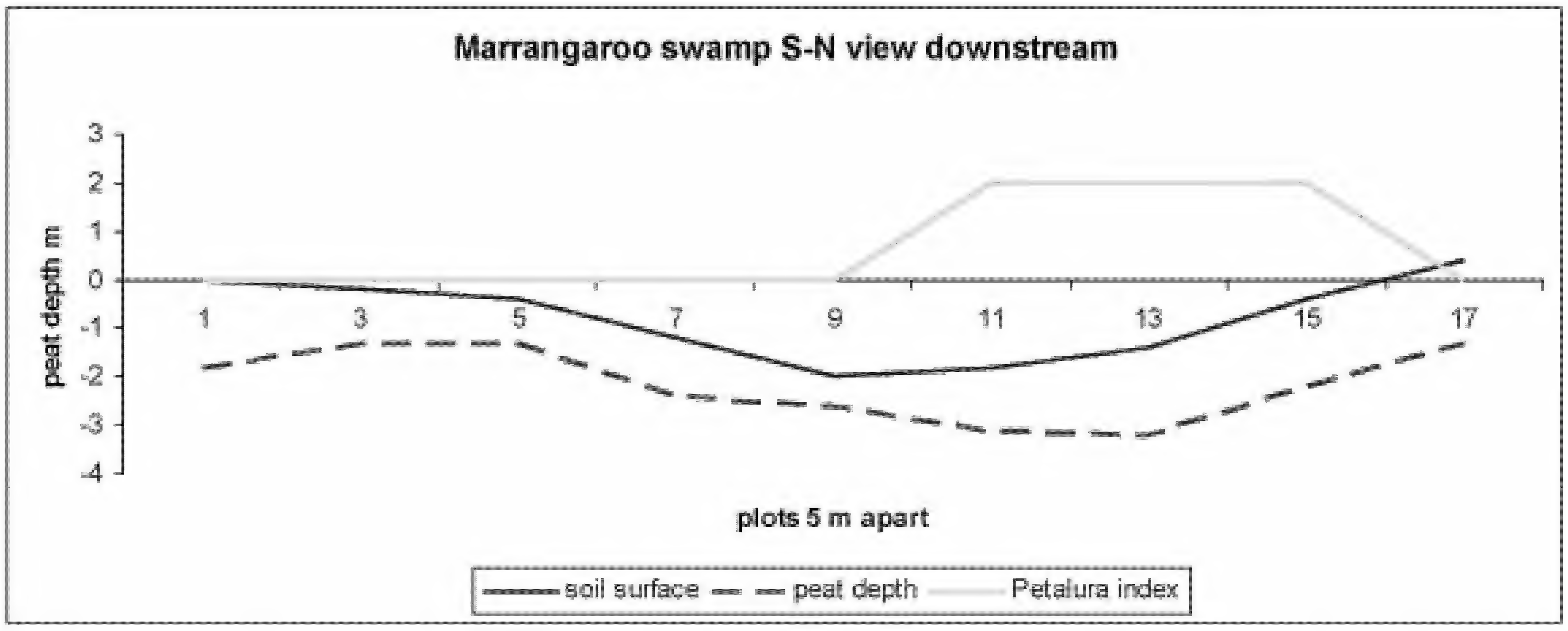


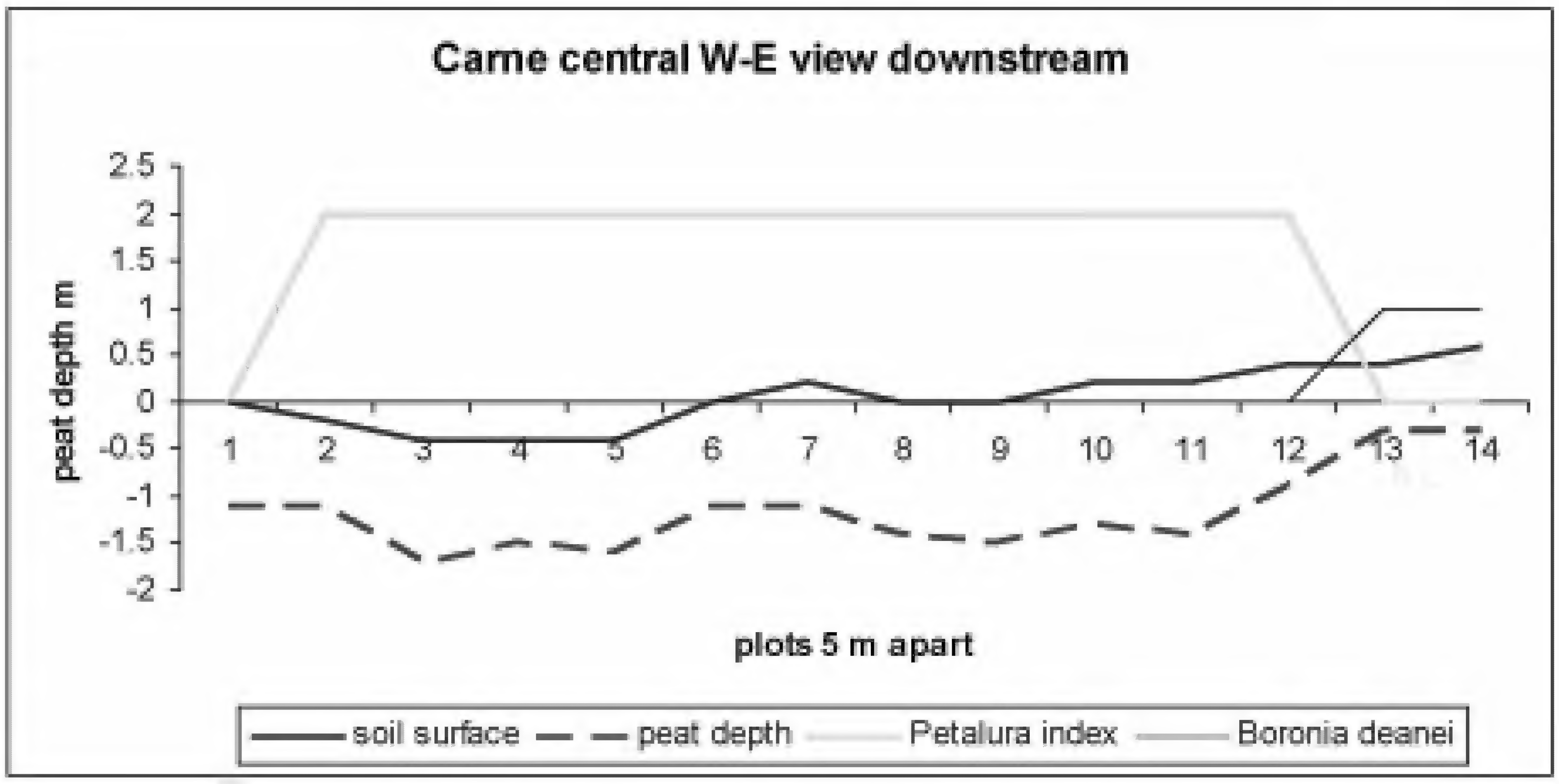


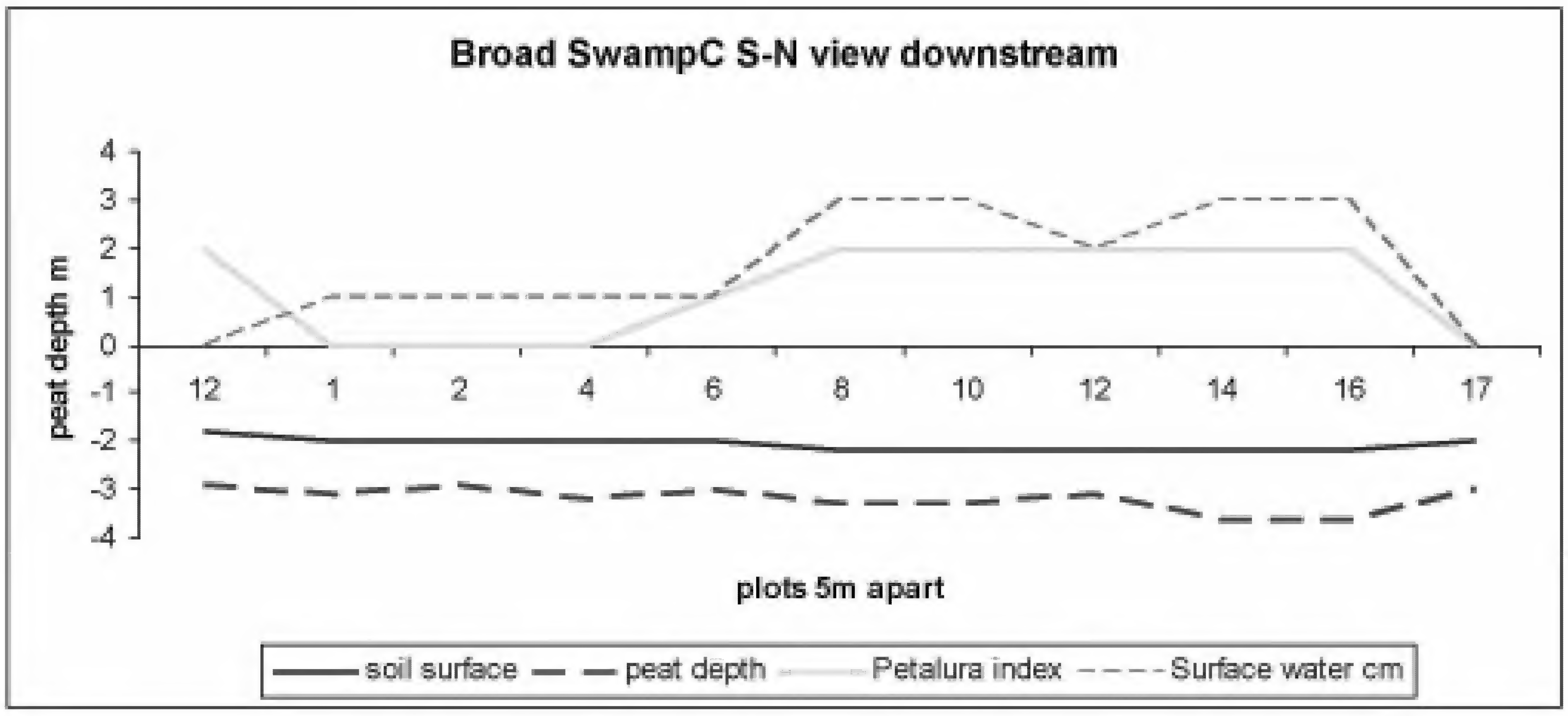

Kangaroo Ck lower E-W view upstream
peat depth m m
0
-1
-2
-3
-4
-5
-6
1
2
3
4
5
6
7
8
9
10
plots E to W 5m apart
soil surface
peat depth

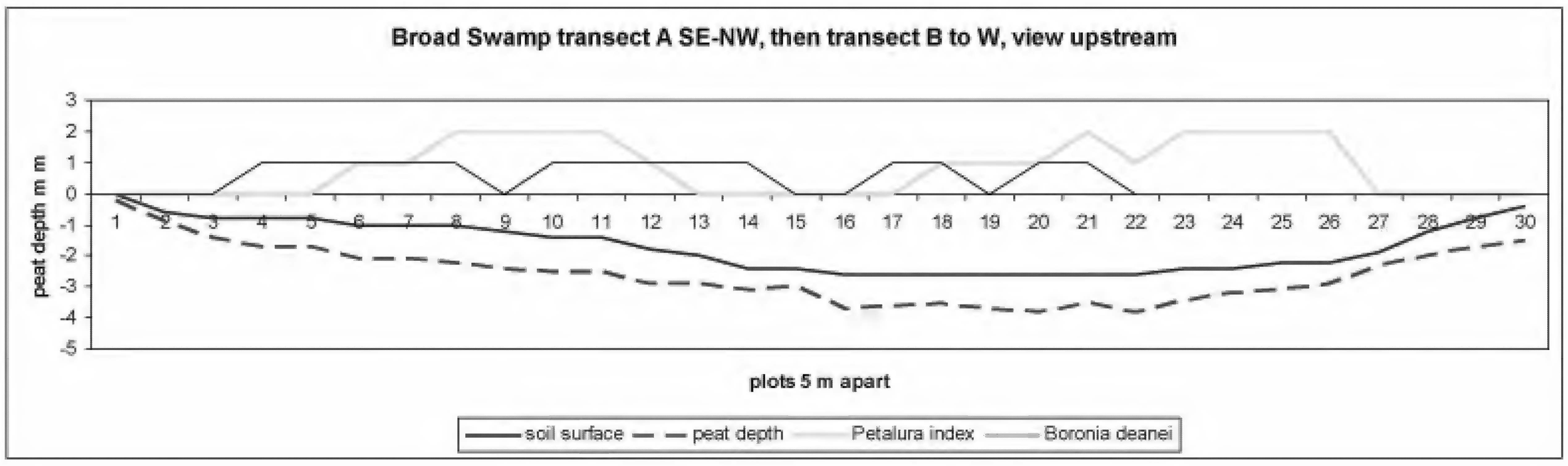

Gang Gang west E to W view upstream
peat depth m
3
2
1
0
-1
-2
-3
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Soil surface
peat depth
Petalura index
Boronia deanei

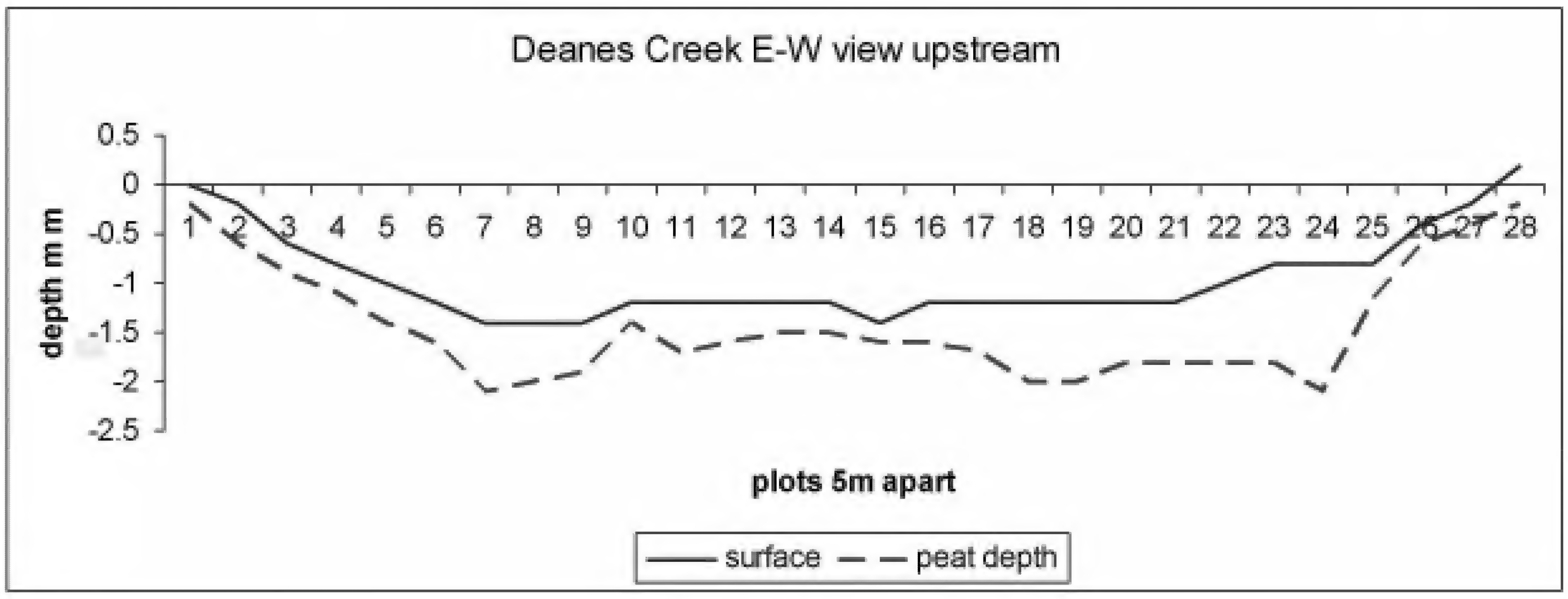

Carne west peat depth E to W view upstream
peat depth m
3
2
1
0
-1
-2
-3
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
soil surface
peat depth
Petalura index


Marrangaroo swamp S-N view downstream
peat depth m
3
2
1
0
-1
-2
-3
-4
1
3
5
7
9
11
13
15
17
plots 5 m apart
soil surface
peat depth
Petalura index


Carne central W-E view downstream
peat depth m
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1 2 3 4 5 6 7 8 9 10 11 12 13 14
plots 5 m apart
soil surface
peat depth
Petalura index
Boronia deanei


Broad SwampC S-N view downstream
peat depth m
4
3
2
1
0
-1
-2
-3
-4
12 1 2 4 6 8 10 12 14 16 17
plots 5m apart
soil surface
peat depth
Petalura index
Surface water cm


Broad Swamp transect A SE-NW, then transect B to W, view upstream
peat depth m m
3
2
1
0
-1
-2
-3
-4
-5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
plots 5 m apart
soil surface
peat depth
Petalura index
Boronia deanei


Deanes Creek E-W view upstream
depth m m
0.5
0
-0.5
-1
-1.5
-2
-2.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
plots 5m apart
surface
peat depth

**Appendix 2 List of plant species recorded from transect plots in Newnes Plateau Shrub Swamps in 2012, showing percentage frequency in each swamp. Swamps are ordered from highest elevation.**

For images of many species see Plants of the Newnes Plateau web pages: www.rbgsyd.nsw.gov.au/science/Evolutionary_Ecology_Research/plants)of_the_newnes_plateau

| | **Kang Ck upper** | **West Wolgan** | **Marangaroo** | **Carne west** | **Kang Ck lower** | **Pine** | **Carne Central** | **Gang Gang west** | **Broad ABC trans** | **Deanes Creek** |
|---|---|---|---|---|---|---|---|---|---|---|
| **No of plots** | **11** | **9** | **9** | **18** | **10** | **7** | **14** | **18** | **40** | **28** |
| **Swamp elevation m** | **1130** | **1130** | **1100** | **1090** | **1090** | **1090** | **1080** | **1080** | **1050** | **980** |
| *Almalea incurvata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Anisopogon avenaceus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| *Baeckea linifolia* | 0 | 44 | 67 | 44 | 0 | 14 | 0 | 67 | 40 | 11 |
| *Baeckea utilis* | 0 | 0 | 0 | 0 | 0 | 0 | 93 | 0 | 30 | 75 |
| *Baloskion australe* | 0 | 33 | 33 | 44 | 10 | 0 | 93 | 11 | 28 | 0 |
| *Banksia cunninghamii* | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 |
| *Banksia spinulosa* | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Baumea* sp | 0 | 0 | 11 | 17 | 0 | 57 | 0 | 11 | 3 | 0 |
| *Blechnum nudum* | 0 | 0 | 0 | 0 | 0 | 43 | 0 | 0 | 0 | 0 |
| *Boronia deanei* | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 6 | 40 | 0 |
| *Boronia microphylla* | 45 | 22 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Bossiaea rhombifolia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Callistemon pityoides* | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Celmisia longifolia* | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 6 | 10 | 0 |
| *Comesperma ericinum* | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Conosperma taxifolium* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 |
| *Coronidium scorpioides* | 9 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Coronidium waddelliae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Dampiera stricta* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 3 | 14 |
| *Daviesia latifolia* | 0 | 11 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 |
| *Dawsonia* sp (moss) | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Dianella revoluta* | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Dichondra repens* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| *Dillwynia stipulifera* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| *Drosera binata* | 0 | 0 | 0 | 11 | 0 | 0 | 7 | 6 | 0 | 0 |
| *Drosera spathulata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 |
| *Empodisma minus* | 0 | 0 | 100 | 89 | 60 | 0 | 100 | 61 | 93 | 0 |
| *Epacris microphylla* | 45 | 78 | 33 | 0 | 10 | 0 | 21 | 22 | 50 | 11 |
| *Epacris paludosa* | 9 | 0 | 33 | 17 | 0 | 0 | 43 | 33 | 45 | 0 |
| *Eucalyptus dalrympleana* | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| *Eucalyptus mannifera* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 5 | 0 |
| *Eucalyptus pauciflora* juv | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| *Gahnia filifolia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 |
| *Gahnia sieberiana* | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 0 |

| | **Kang Ck upper** | **West Wolgan** | **Marangaroo** | **Carne west** | **Kang Ck lower** | **Pine** | **Carne Central** | **Gang Gang west** | **Broad ABC trans** | **Deanes Creek** |
|---|---|---|---|---|---|---|---|---|---|---|
| **No of plots** | **11** | **9** | **9** | **18** | **10** | **7** | **14** | **18** | **40** | **28** |
| **Swamp elevation m** | **1130** | **1130** | **1100** | **1090** | **1090** | **1090** | **1080** | **1080** | **1050** | **980** |
| *Galium* sp | 0 | 11 | 0 | 0 | 0 | 0 | 7 | 0 | 10 | 0 |
| *Gleichenia dicarpa* | 55 | 0 | 89 | 78 | 90 | 100 | 0 | 56 | 20 | 0 |
| *Gonocarpus micranthus* | 0 | 44 | 22 | 6 | 0 | 0 | 64 | 0 | 3 | 39 |
| *Gonocarpus tetragynus* | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 7 |
| *Goodenia belledifolia* | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 11 | 13 | 7 |
| *Grevillea acanthifolia* | 0 | 0 | 89 | 56 | 20 | 0 | 64 | 22 | 58 | 0 |
| *Grevillea laurifolia* | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Gymnoschoenus sphaerocephalus* | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 44 | 23 | 18 |
| *Hakea microcarpa* | 0 | 78 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Hibbertia acicularis* | 0 | 0 | 56 | 0 | 0 | 0 | 0 | 6 | 5 | 0 |
| *Hibbertia* sp (*riparia*??) | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Hydrocotyle peduncularis acicularis* | 0 | 11 | 0 | 0 | 20 | 0 | 14 | 0 | 3 | 4 |
| *Hypericum gramineum* | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| *Hypochoeris radicata** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| *Juncus* sp | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 |
| *Lepidosperma laterale* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| *Lepidosperma limicola* | 0 | 0 | 67 | 50 | 0 | 14 | 0 | 72 | 43 | 29 |
| *Leptospermum continentale* | 27 | 33 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| *Leptospermum grandifolium* | 9 | 0 | 11 | 44 | 0 | 0 | 0 | 56 | 68 | 18 |
| *Leptospermum myrtifolium* | 100 | 56 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 |
| *Leptospermum obovatum* | 0 | 0 | 0 | 0 | 40 | 0 | 7 | 0 | 0 | 0 |
| *Lepyrodia anarthria* | 0 | 33 | 33 | 11 | 0 | 0 | 7 | 6 | 20 | 21 |
| *Lepyrodia scariosa* | 0 | 0 | 0 | 0 | 0 | 14 | 0 | 6 | 0 | 4 |
| *Lindsaea linearis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 20 | 0 |
| *Lomandra glauca* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 3 | 4 |
| *Lomandra longifolia* | 0 | 22 | 0 | 0 | 10 | 0 | 0 | 0 | 8 | 7 |
| *Microlaena stipoides* | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Mirbelia platyloboides* | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Monotocca scoparia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Nertera granadensis* | 0 | 44 | 0 | 0 | 0 | 0 | 21 | 28 | 13 | 4 |
| *Patersonia fragilis* | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 60 | 0 |
| *Patersonia sericea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Persoonia hindii* | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Petrophile canescens* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Phyllota squarrosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 3 | 4 |
| *Pimelea linifolia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 |
| *Platysace linearifolia* | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 6 | 0 | 0 |
| *Poa* sp | 36 | 22 | 0 | 6 | 10 | 0 | 0 | 0 | 23 | 0 |
| *Polyscias sambucifolia* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |

| | **Kang Ck upper** | **West Wolgan** | **Marangaroo** | **Carne west** | **Kang Ck lower** | **Pine** | **Carne Central** | **Gang Gang west** | **Broad ABC trans** | **Deanes Creek** |
|---|---|---|---|---|---|---|---|---|---|---|
| **No of plots** | **11** | **9** | **9** | **18** | **10** | **7** | **14** | **18** | **40** | **28** |
| **Swamp elevation m** | **1130** | **1130** | **1100** | **1090** | **1090** | **1090** | **1080** | **1080** | **1050** | **980** |
| *Poranthera microphylla* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| *Pteridium esculentum* | 0 | 0 | 0 | 6 | 40 | 0 | 0 | 0 | 0 | 4 |
| *Pultenaea divaricata* | 0 | 0 | 33 | 17 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Rulingia prostrata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| *Schoenus* sp (larger) | 0 | 0 | 11 | 0 | 0 | 0 | 14 | 0 | 0 | 0 |
| *Schoenus* sp (small) | 9 | 0 | 11 | 0 | 0 | 0 | 57 | 0 | 0 | 0 |
| *Selaginella uliginosa* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 |
| *Sprengelia incarnata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 |
| *Stackhousia viminea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Stylidium graminifolium* | 36 | 11 | 0 | 0 | 0 | 0 | 0 | 11 | 10 | 32 |
| *Tetrarrhena juncea* | 0 | 0 | 22 | 0 | 0 | 0 | 14 | 6 | 10 | 0 |
| *Thelymitra* sp | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 3 | 4 |
| *Utricularia dichotoma* | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 6 | 3 | 0 |
| *Velleia montana* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 |
| *Viola betonicifolia* | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Viola sieberiana* | 64 | 44 | 11 | 6 | 0 | 0 | 14 | 0 | 0 | 46 |
| *Wahlenbergia gracilis* | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Xanthosia dissecta* | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 11 | 13 | 0 |
| *Xyris gracilis* | 0 | 44 | 0 | 0 | 0 | 0 | 0 | 6 | 3 | 7 |
| *Xyris ustulata* | 0 | 0 | 22 | 39 | 0 | 0 | 14 | 50 | 25 | 36 |

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# Vegetation structure and floristics of granite landforms in the South-west Slopes of New South Wales

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***Abstract:*** We describe the natural vegetation structure and floristics of 44 small-sized granite outcrops (inselbergs) in agricultural landscapes in the South-west Slopes (SWS) bioregion of New South Wales (35º 26' S, 147º 23' E to 35º 58' S, 146º 59'E) and their relationships with geomorphology. We provide a list of 196 species (117 natives and 79 exotics). We found that structurally complex outcrops supported a greater diversity of native ground cover species and fewer exotic species than structurally simple outcrops. Tor landforms lacked vegetation structural complexity and were deficient in native shrubs, mid-storey and over-storey species but typically supported exotic grasses and broad-leaved exotic weeds. Floristic composition differed among landforms and cluster analysis revealed highly dissimilar native plant communities among outcrops. Our study highlights the need to rehabilitate tor landforms and manage a broad spectrum of outcrops to conserve floristic diversity in agricultural landscapes. Selecting genetically diverse species for replanting, considering the density and spatial arrangement of plantings, and controlling invasive plants and feral herbivorous animals are fundamental issues in restoring granite outcrop vegetation in the SWS bioregion.

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## Introduction

Inselbergs are granite outcrops that rise abruptly from flat landscapes (Twidale 1982) providing a broad range of micro-climatic conditions that contrast with surrounding landscapes (Campbell 1997) and supporting biologically diverse communities (Porembski & Barthlott 2000). For these reasons, the biota of inselbergs have fascinated scientists from around the world for over 200 years (Walters 1982), not least because these environs are rich in endemic taxa (Porembski & Barthlott 2000), but also because they provide a model framework for examining patterns of floristic diversity and species composition in the context of island biogeography theory (Burke 2003, Butler & Fensham 2008, Michael et al. 2008). However, in many parts of the world, agricultural development and the associated impacts of habitat fragmentation is threatening the natural insularity of inselbergs by creating smaller habitat isolates, and increasing isolation by reduced vegetation connectivity. This process has serious implications for the long-term viability of plant populations in modified landscapes (Broadhurst & Young 2006, Broadhurst *et al.* 2008).

An important aspect of inselberg ecology is their role in providing refugia for endemic and fire sensitive flora. Fires on granite outcrops are generally rare due to the buffering effect of rock (Burke 2003), and in the absence of fire, fire-sensitive and mesic-adapted plants such as ferns grow in sheltered locations (Hopper et al. 1997). Many outcrops

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support obligate seeders (Hopper 2000, Hunter 2003) such as *Callitris* spp., *Acacia* spp., *Pultenaea* spp. and *Dodonaea* spp. which germinate following fire, in contrast to sprouters which regenerate primarily from epicormic buds or underground rhizomes, such as many *Eucalyptus* spieces (Clarke 2002). In sclerophyllous vegetation, frequent high-intensity fires promote sprouters whereas intermediate low-intensity fires promote obligate seeders (Keith 1996). Frequent fires can therefore alter plant species composition, a process which can threaten the integrity and long-term persistence of outcrop flora (Bradstock et al. 2002).

The grassy box woodlands of temperate south-eastern Australia represent a broad bio-climatic region that has been extensively modified (Beadle 1981) and continues to be threatened by agricultural intensification and urban development (Yates & Hobbs 1997, Lindenmayer et al. 2010). It is estimated that less than 5% of the original grassy box woodland remains intact (Prober 1996), with much of the remaining vegetation occurring on skeletal soils and rocky outcrops. The South-west Slopes (SWS) botanical region of New South Wales is one of the most heavily cleared bioregions in New South Wales (Benson 2008). Grassy box woodlands are significantly fragmented; improvements to the condition and extent of remnant vegetation are a priority conservation action of natural resource management agencies (Murray Catchment Management Authority 2007). If it were not for an archipelago of rocky outcrops in the SWS, the majority of which are granite, grassy box woodland may have been more extensively cleared than current vegetation patterns suggest.

In Western Australia, inselberg vegetation has been the subject of considerable research (Smith 1962, Burgman 1987, Ornduff 1987, Hopper et al. 1997, Ohlemuller 1997, Porembski et al. 1997, Pigott 2000, Porembski 2000), whereas inselbergs in eastern Australia have received far less attention (Ashton & Webb 1977, Norris & Thomas 1991, Hunter & Clarke 1998). The value of granite outcrops in supporting rock-dwelling reptiles in agricultural landscapes has been reported recently in the SWS (Michael et al. 2008, Michael et al. 2010a), and specific management actions have been proposed to enhance habitat for this group (Michael et al. 2010b). Given the paucity of vegetation studies in the SWS (Burrows 1999), additional studies are required which may help inform restoration activities in the region. The main aim of this study was to examine vegetation patterns and floristic composition of relatively small granite outcrops in relation to different landforms. It is widely recognized that vegetation communities change in response to lithology (Norris & Thomas 1991, Burrows 1999). However, the influence of geological landform on patterns of vegetation is less well understood (Kruckenburg 2002). We frame our study by proposing three main questions. 1) Do current patterns of vegetation structure differ among landforms of the same geology? 2) Is floristic composition influenced by granite landform? 3) Can these findings help guide conservation and restoration activities in the SWS bioregion?

## Methods

### *Study area*

This study area was in the southern half of the South-west Slopes (SWS) bioregion of New South Wales, bordered by Big Springs in the north (35° 19' S, 147° 25' E), Albury in the south (36° 00' S, 146° 53'E), Kyeamba in the east (35° 26' S, 147° 37'E) and Goombargana in the west (35° 44' S, 146° 34'E). Annual average rainfall in the region ranges from approximately 450 mm at Walbundrie to 550 mm near Tarcutta (Bureau of Meterology 2012). Due to drought conditions the average monthly precipitation during the study period, Oct 2006 – Feb 2007, was generally below average for each month (2006 Oct– 2.4 mm, Nov– 46.2 mm, Dec– 1.6 mm; 2007 Jan– 36.5 mm, Feb– 40.8 mm, Bureau of Meterology 2012). The vegetation type is temperate woodland (*sensu* Hobbs & Yates 2000), dominated by the endangered ecological vegetation community – White box *(Eucalyptus albens)*, Yellow box (*Eucalyptus melliodora)*, Blakely's red gum (*Eucalyptus blakelyi)* woodland (www.environment.gov.au 2012).

Granitoid formations associated with the Southern Highlands Fold Belt (Wagga Metamorphic Belt) are one of the main lithologies in the SWS (Packham & Day 1969). Soils derived from surface weathering of granite produces a shallow layer of sandy loam that overlays sandy clay (Norris & Thomas 1991). Four geomorphologically distinct granite landforms (*sensu* Campbell 1997; see Michael et al. 2008 for images) occur in the region. These are:

(1) Bornhardt / Dome (6 outcrops) – large, steep-sided dome-shaped hills arising abruptly from the surrounding landscape characterized by large expanses of bare rock. Shallow and elliptical bornhardts are called 'whalebacks' or 'turtlebacks'.

(2) Nubbin (13 outcrops) – small, conical hills rising gently from the surrounding landscape, characterized by small boulder-strewn rock piles.

(3) Castle koppie (8 outcrops) – small, steep-sided hills arising abruptly from the surrounding landscape characterized by large orthogonally fractured boulder stacks.

(4) Tors (17 outcrops) – sparsely aggregated rocks in flat or gently undulating landscapes characterized by individual, block-shaped pillars of various sizes.

### *Sampling protocol*

Between October 2006 and February 2007, one of the authors (DM) assessed vegetation on 44 privately owned granite outcrops located within agricultural landscapes. Subsets of all four landforms were surveyed each month over the assessment period. With the exception of three outcrops where livestock had been excluded prior to the study, grazing pressure included set stocking rates (N = 25 outcrops) or rotational grazing regimes (N = 16 outcrops). On each outcrop, we established a 1 hectare (100 m x 100

**Table 1. Summary of geological and floristic attributes for each granite landform in the SWS bioregion (Bold numbers indicate relatively high or low attribute values).**

| | Nubbin | Koppie | Tor | Bornhardt |
|---|---|---|---|---|
| **Geomorphological attributes** | | | | |
| Number surveyed | 13 | 8 | 17 | 6 |
| Mean outcrop size (ha) | 4.9 | 4.2 | 3.2 | **57.1** |
| Median outcrop size (ha) | 4 | 5 | 1.5 | **17.5** |
| Exposed rock cover (%) | 45 | 55 | 31 | 50 |
| **Vegetation structural attributes** | | | | |
| Total stem density (stems/ha) | 54.4 | 42.5 | **10.4** | 60.3 |
| Density of regrowth (DBH < 20 cm) | 28.1 | 24.6 | **2.3** | 30.5 |
| Density of oldgrowth (DBH > 60 cm) | 2.4 | 3.4 | 3.5 | 2.4 |
| Native overstorey cover (%) | 19 | 17 | **5** | 28 |
| Native shrub cover (%) | 31 | 13 | **1** | 0.8 |
| Total grass cover (%) | 28 | 23 | **48** | 28 |
| **Floristics** | | | | |
| Mean native species richness | 18 | 18 | 12 | 14 |
| Mean exotic species richness | 9 | 12 | 11 | 8 |

m) grid and recorded plant species richness over a two hour period by assessing areas with soil, rock crevices and ledges. The average amount of exposed rock within each quadrat ranged from 30% on tors to 60% on koppies. In addition, we recorded structural attributes such as overstorey density (live and dead), overstorey stem diameter size class (0 – 20 cm, 21 – 40 cm, 41 – 60 cm and > 60 cm), midstorey height class (0 – 0.5 m, 0.51 – 1.0 m, 1.1 – 2.0 m and > 2 m), percent cover estimates for individual species (overstorey, midstorey and understorey shrubs), percent cover estimates for native and exotic grass cover, native and exotic forbs, woody weeds, rock cover, leaf litter and bare ground. We also recorded the number of logs, stumps and fallen trees in our 1 ha plots. We identified species using Harden (1990 –2002) and followed the nomenclature of PlantNET (www.Plantnet.com.au).

For the outcrops in this study the median patch size was 4 ha (mode = 5 ha, mean = 11 ha, range 0.5 – 201 ha) which meant in many cases our sampling area covered a large proportion of the outcrop. We assigned each outcrop a structural complexity score ranging from 1 – 5 based on the tally of rocks in six volumetric categories (flat expanses of rock, rocks < 0.5 m³; boulders between 0.5 m³ – 2 m³, pillars between 2 m³ – 5 m³, blocks between 5 m³ – 10 m³; and domes > 10 m³, see Michael et al. 2008).

### *Statistical analysis*

We completed non-parametric data analysis using options available in Excel, SPSS v7 and Primer v6 (Clarke & Gorley 2006). We standardized our data to site level and compared species richness, structural attributes and cover

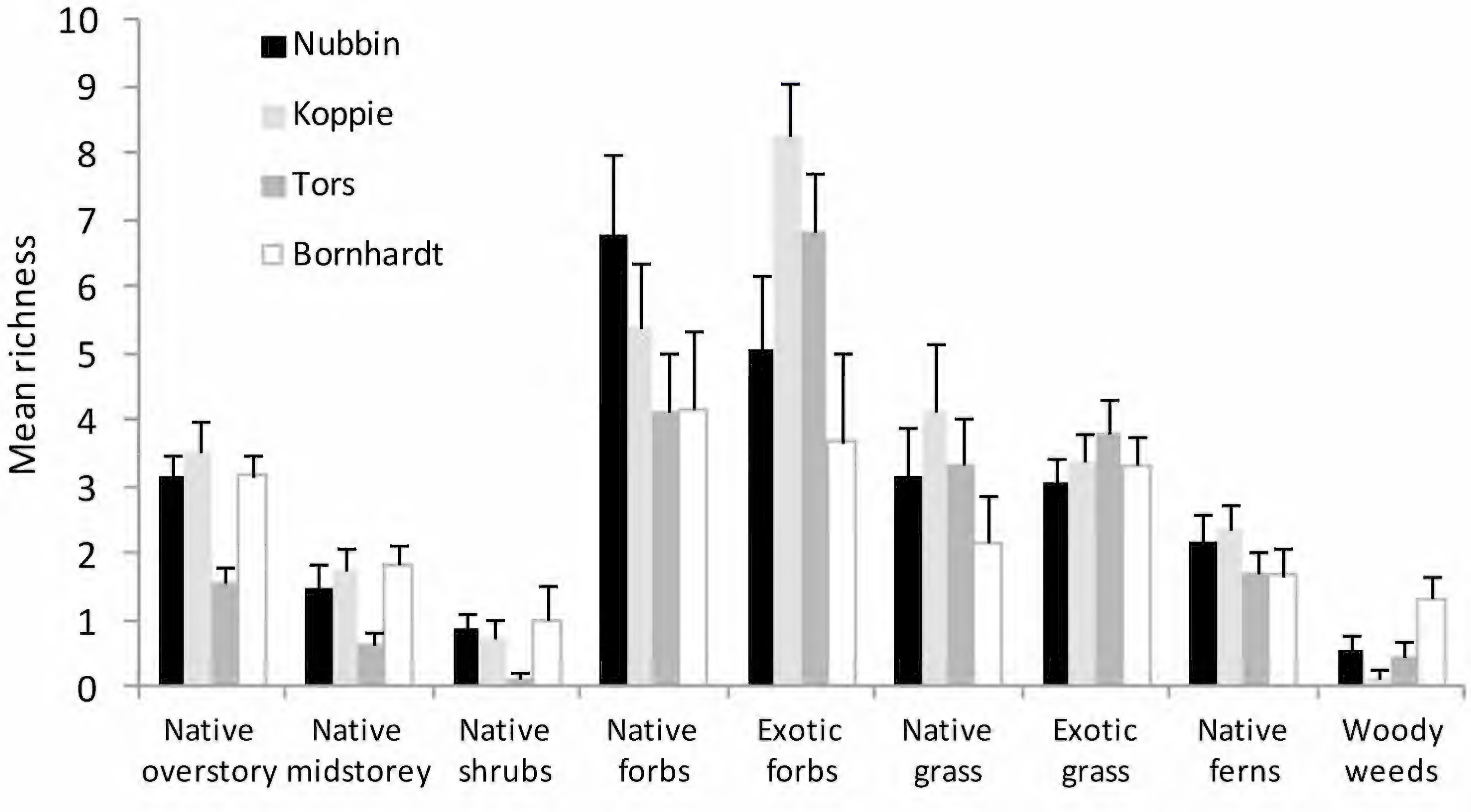

**Fig. 1.** Variation in mean species richness (±1 SE) for nine floristic groups on four granite landforms in the NSW South-west Slopes.

abundance estimates among landforms using ANOVA. We used presence/absence data to construct a similarity matrix for all species, native and exotic taxa, and compared floristic composition among landforms (ANOSIM), with 9999 random permutations of the data. We used the Jaccard coefficient of similarity to perform hierarchical cluster analysis (Clarke & Gorley 2006).

## Results

We recorded a total of 196 vascular plant species (117 native and 79 exotic species) including eight *Eucalyptus* species, six *Acacia* species, 45 native forbs, 20 native grasses, 21 exotic grasses, 47 exotic forbs / broad-leaved weeds, and 11 woody weeds (Appendix 1). The dominant families Poaceae and Asteraceae accounted for 36% of all species. Common overstorey species included *Eucalyptus albens* (55% of sites), *Acacia implexa* (57%), *Eucalyptus blakelyi* (50%) and *Brachychiton populneus* (48%). *Indigofera australis* was the most common shrub (16%). The most common ground cover species included *Isotoma axillaris* (75%), **Acetosella vulgaris* (62%), **Hordeum leporinum* (61%), *Cheilanthes austrotenuifolia* (61%), **Bromus diandrus* (55%), *Oxalis perennans* (55%), **Echium plantagineum* (52%), *Pleurosurus rutifolius* (48%), *Austrodanthonia caespitosa* (48%), **Avena fatua* (46%), **Hypochaeris radicata* (43%), **Vulpia myuros* (39%) and *Bothriochloa macra* (39%). One threatened species, *Senecio garlandii* was recorded on two sites. (* above indicates exotic species).

### *Species richness*

We found that plant species richness did not differ significantly among landforms (F 3, 40 = 0.8, P = 0.49) and ranged from 22 species on bornhardts to 30 species on

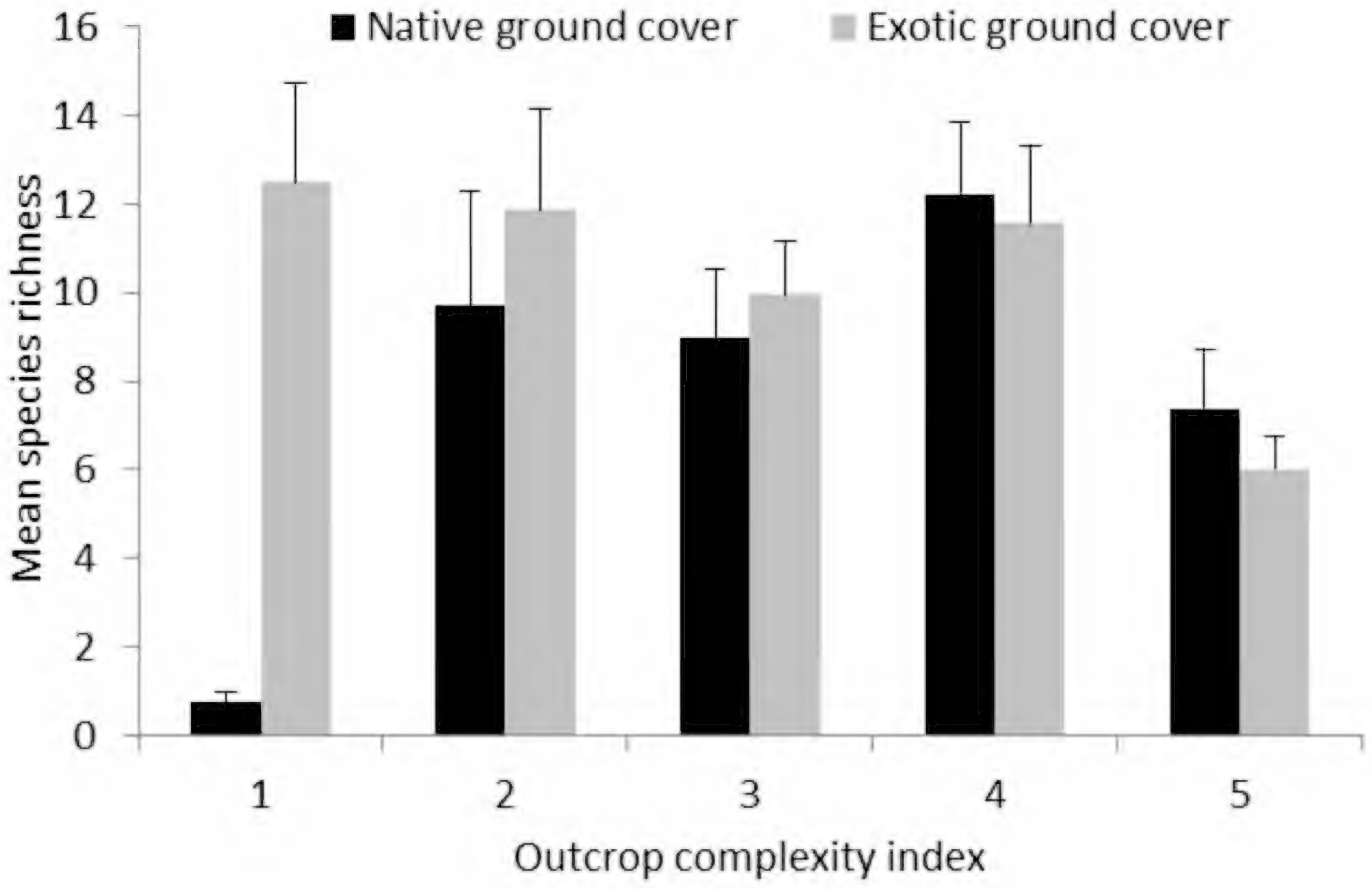

**Fig. 2.** Variation in mean richness of native and exotic ground cover species (±1 SE) among granite outcrops of varying structural complexity in the NSW South-west Slopes.

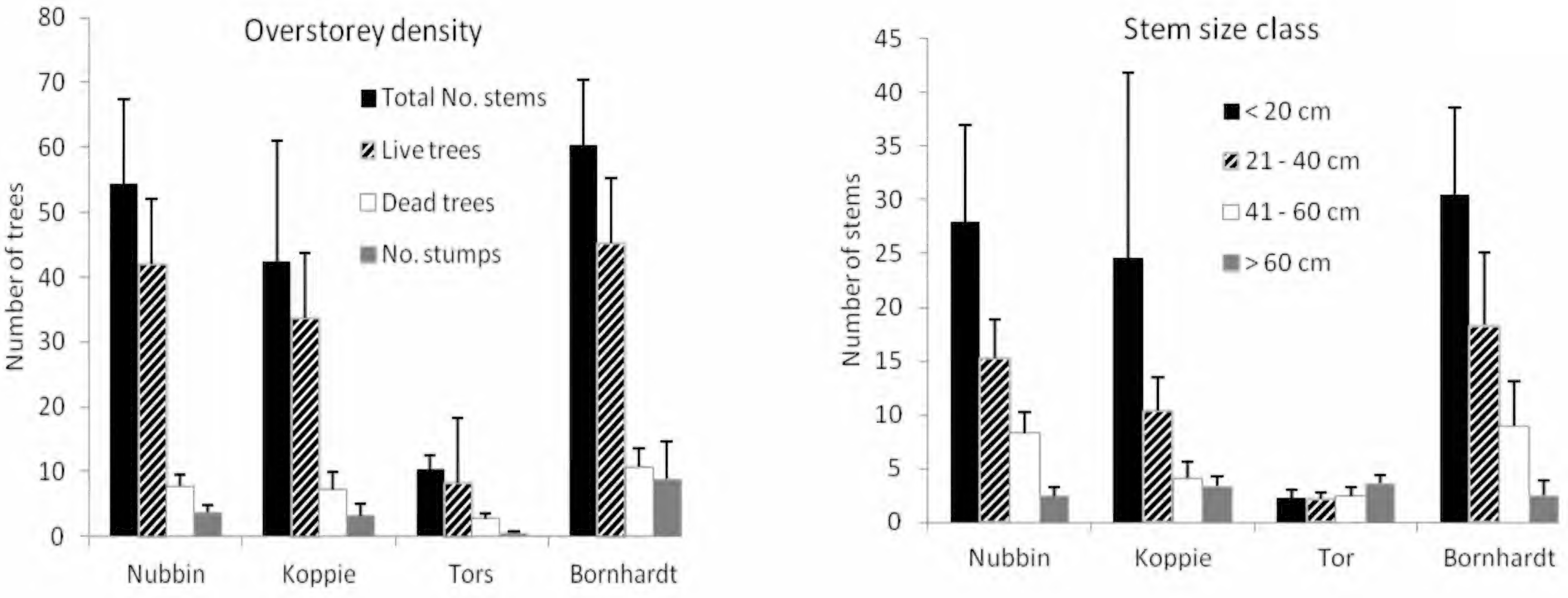

**Fig. 3.** Variation in the mean density (±1 SE) of overstorey attributes among granite landforms in the NSW South-west Slopes.

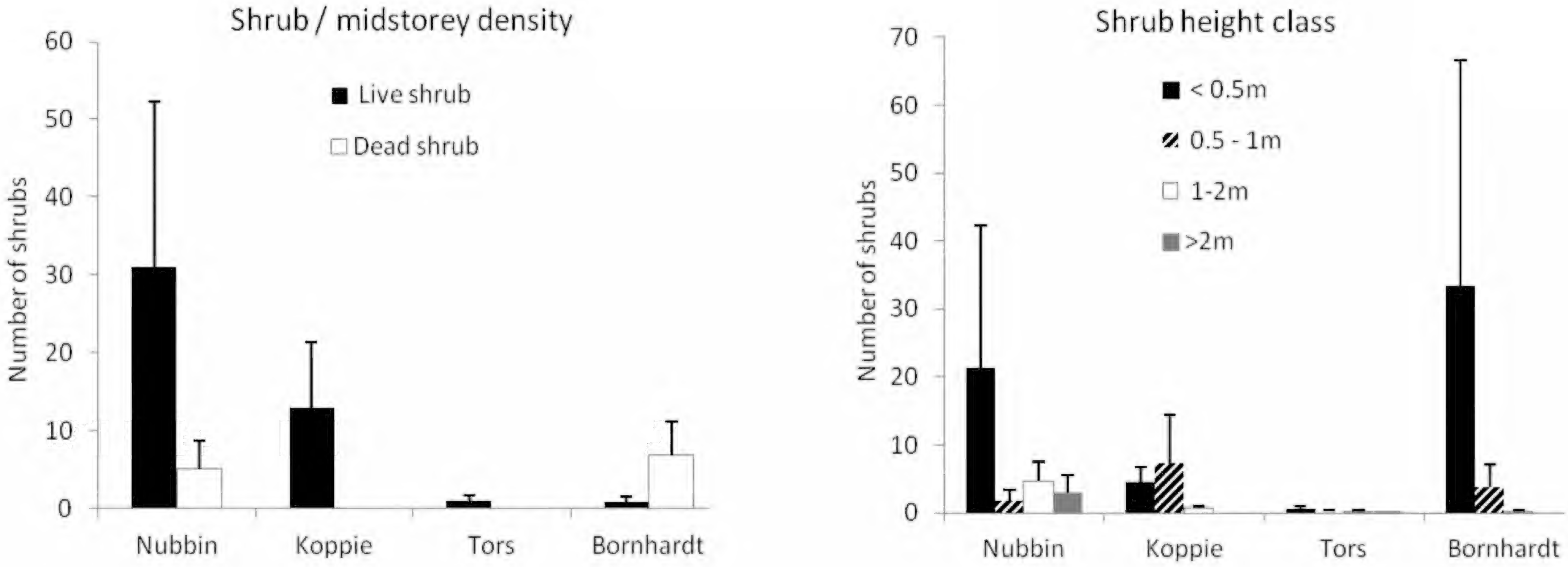

**Fig. 4.** Variation in the mean density (±1 SE) of midstorey attributes among granite landforms in the NSW South-west Slopes.

koppies (Table 1). Of floristic groups, native overstorey (F 3, 40 = 8.89, P < 0.001), midstorey (F 3, 40 = 3.47, P = 0.02) and native shrub species richness (F 3, 40 = 3.11, P = 0.03) differed significantly among landforms, with tors supporting the least number of species in all three groups (Figure 1). The number of exotic forbs and woody weeds also varied among landforms (Figure 1), although these differences were not significant (exotic forbs F 3, 40 = 2.5, P = 0.07, woody weeds F 3, 40 = 2.71, P = 0.057).

### *Relationship between outcrop complexity and species richness*

We found a significant positive linear relationship between native ground cover species richness and outcrop structural complexity ($R^2 = 0.3$), where native species richness increased as a function of complexity. On average, structurally simple outcrops supported one or less native species, whereas complex outcrops supported more than 12 native species (Figure 2). In contrast, we found a strong negative linear relationship between exotic ground cover species richness and outcrop structural complexity ($R^2 = 0.6$), where exotic species richness decreased as a function of outcrop complexity. On average, structurally simple outcrops supported more than 12 exotic species, whereas, complex outcrops supported half that number (Figure 2).

### *Vegetation structure*

We found a significant difference in several overstorey attributes among landforms, including total number of stems (F test 3, 40 = 5.19, P = 0.004), number of live trees (F test 3, 40 = 4.26, P = 0.01), number of dead trees (F test 3, 40 = 3.70, P = 0.02), and number of tree stumps (F 3, 40 = 2.92, P = 0.04). These results were influenced by tor landforms supporting the lowest value for all four variables mentioned

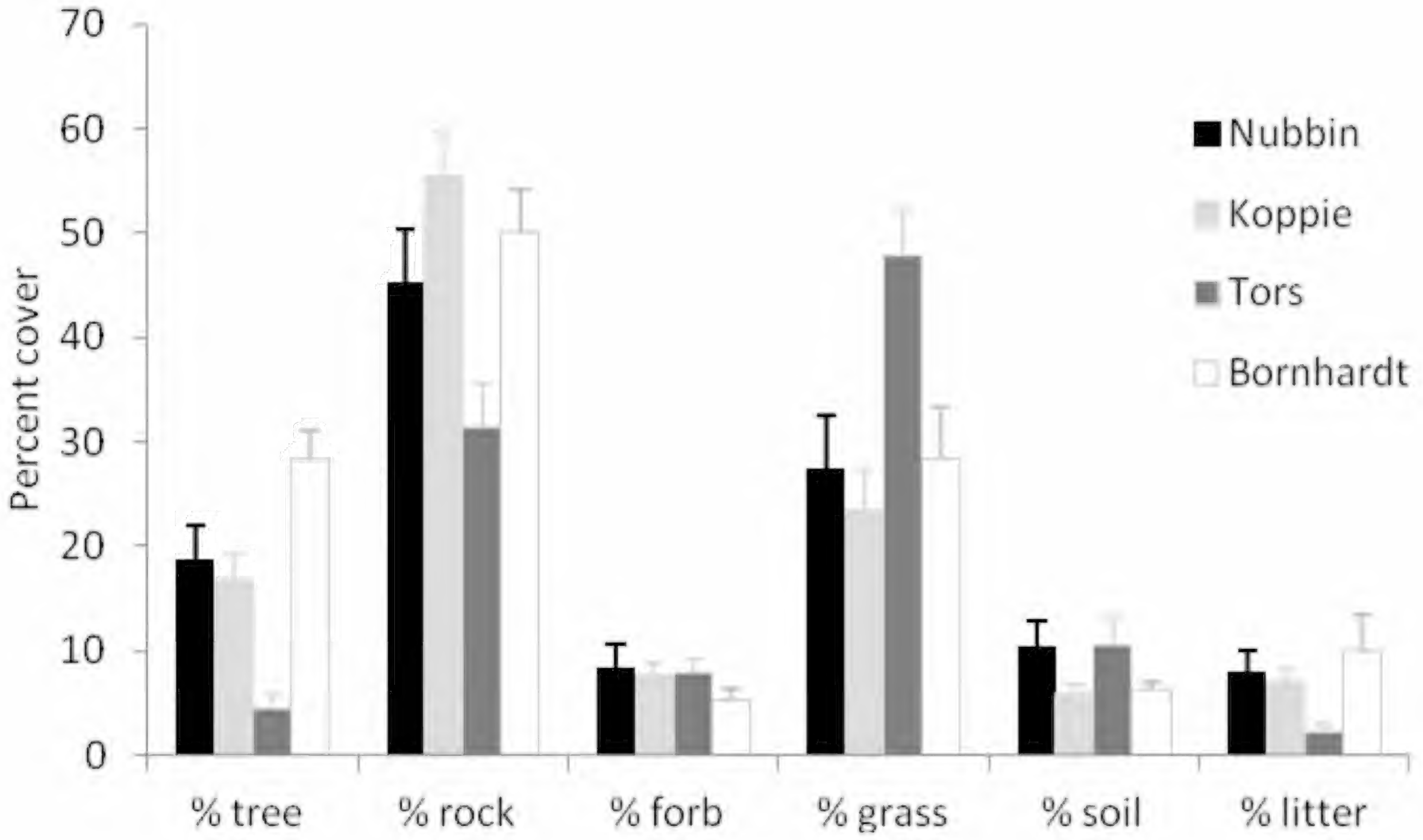

**Fig. 5.** Variation in percent cover abundance estimates (±1 SE) for biotic and abiotic variables among granite landforms in the South-west Slopes of New South Wales.

above (Figure 3). The mean number of stems in several diameter size classes also differed significantly among landforms, particularly for number of stems less than 20 cm (F 3, 40 = 2.88, P = 0.04), between 21 and 40 cm (F 3, 40 = 6.24, P < 0.001) and between 41 and 60 (F 3, 40 = 3.27, P = 0.003). These differences were attributed to the low number of stems in all size classes on tor landforms (Figure 3).

We found the mean total number of shrub and midstorey plants did not differ significantly among landforms, although both nubbins and koppies supported an average density of 31 and 13 midstorey plants respectively (nubbin range = 0 – 271 plants / ha, koppie range = 0 – 69 plants / ha) (Figure 4). In addition, the number of shrub and midstorey plants in four height classes did not differ significantly among landforms (Figure 4).

We found a significant difference in mean percent cover abundance estimates between landforms (Figure 5). These included overstorey tree cover (F 3, 40 = 13.72, P < 0.001) which was highest on bornhardts and lowest on tors, grass cover (F 3, 40 = 5.67, P = 0.002) which was highest on tors, and leaf litter cover (F 3, 40 = 3.25, P 0.03) which was lowest on tors.

### *Floristic composition*

Analysis of similarity (ANOSIM) revealed floristic composition varied significantly among landforms when all species were included (Global R statistic = 0.13, *P* = 1%), and for exotic species (Global R statistic = 0.14, *P* = 3%), but not for native species (Global R statistic = 0.04, *P* = 21%) or just native perennials (Global R statistic = 0.02, *P* = 33%). When all species were included, hierarchical cluster analysis revealed high levels of floristic dissimilarity among outcrops, with the majority of outcrops sharing less than 30% of total species. When exotic species were excluded, cluster analysis showed the majority of outcrops shared less than 40% of species, and when only native perennials were included, cluster analysis showed the majority of outcrops shared less than 45% of species (Figure 6).

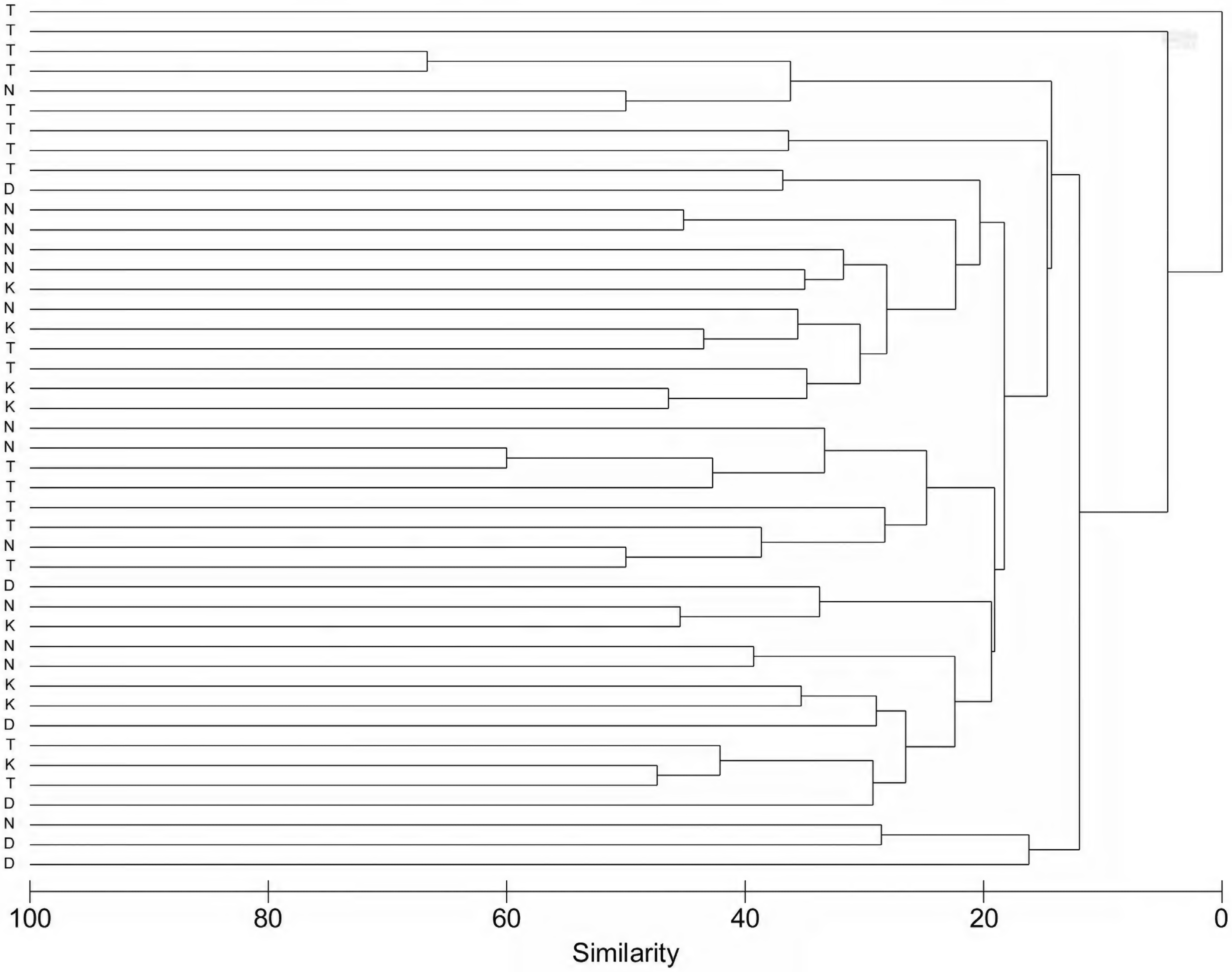

**Fig. 6.** Heirarchical cluster analysis showing community similarity for native perennial species (Jaccard similarity co-efficient) among outcrops classified by geomorphology in the South-west Slopes of New South Wales (N = nubbin, K = koppie, T = tor, and D = Dome / bornhardt).

## Discussion

Granite inselbergs represent unique environments for plant survival and are typically rich in floristic diversity and endemic taxa (Hopper et al. 1997, Hunter & Clarke 1998), but there are few studies on small granite outcrops in south-eastern Australia (see Norris & Thomas 1991). This study was conducted during the spring and summer months of a prolonged period of drought, thereby spanning a non-optimal survey period for detecting native annual plant species (Burrows 2004). Nevertheless, we recorded 197 species (Appendix 1), including a new record with approximately 50 individuals of the daisy *Senecio garlandii* (Asteraceae family), a threatened species listed as Vulnerable under the *NSW Threatened Species Conservation Act 1995*. *Senecio garlandii* is currently known from nine locations in the SWS (Burrows 2001). *Senecio garlandii* (Asteraceae) was recorded growing near the base of outcrops 6.8 km west of Gerogery and near Big Springs (19 km south of Wagga Wagga). Several regionally significant species were recorded. *Correa glabra* (Rutaceae) was recorded from the summit of Mount Budginni near the locality of Tabletop, 8 km north of Albury CBD. *Pultenaea platyphylla* (Fabaceae) was recorded from rock crevices on two outcrops 13 km west of Gerogery. *Acacia penninervis* (Mimosaceae) was recorded growing on the summit of Mount Mullemba (8.4 km north of Walbundrie) and an outcrop near Big Springs (27 km south of Wagga Wagga) and *Santalum apiculatum* (Santalaceae) was recorded on an outcrop 10 km east of Henty and 9.4 km south of Walla Walla.

Additional key findings include: 1) marked differences in mid and overstorey species richness, vegetation structure and floristic composition among granite landforms; 2) multi-directional relationships between the ratio of native and exotic groundcover species and outcrop structural complexity, and 3) high levels of floristic dissimilarity among outcrops. However, because some of our surveys were conducted during less optimal periods of the year for detecting annual forb and grass species in the SWS (Burrows 2004), our results should be interpreted with caution. We discuss the management implications of our findings below and conclude with recommendations to help guide future restoration programs in the SWS bioregion.

### *Species richness and vegetation structure*

Inherent differences in physical complexity among landforms mean outcrops are differentially affected by agricultural practices. The majority of outcrops in the study region supported remnants of the endangered ecological vegetation community; white box *Eucalyptus albens*, yellow box *Eucalyptus melliodora*, Blakely's red gum *Eucalyptus blakelyi* woodland, although species richness, vegetation cover and condition varied among landforms. In general, tor landforms were dominated by exotic grasses and forbs (Figure 1), lacked shrubs (Figure 4) and supported less than 5% tree cover (Figure 5). By contrast, complex outcrops supported greater plant diversity (Figure 2), multiple strata, and more vegetation cover (Figure 5). Tor landforms are the highly eroded remnants of bornhardts and consequently occur in relatively flat, productive landscapes (Twidale 1982). Historically, native vegetation growing on the most productive soils has been extensively cleared for agriculture, whereas native vegetation growing on poorer soils has often survived relatively intact, but exposed to disturbances such as fire, logging and livestock grazing (Prober & Thiele 2004). Fire can cause *Eucalyptus* species to resprout from basal lignotubers (Gill 1981, Noble 2001), whereas logging activities often leave behind cut stumps which resprout above the ground (Figure 7) (Wildy et al. 2000). Both regeneration pathways can produce cohorts of multi-stemmed trees. The high density of small-sized overstorey stems (less than 20 cm) and tree stumps on nubbins and koppies (Table 1) is indicative of previous fire and logging activities.

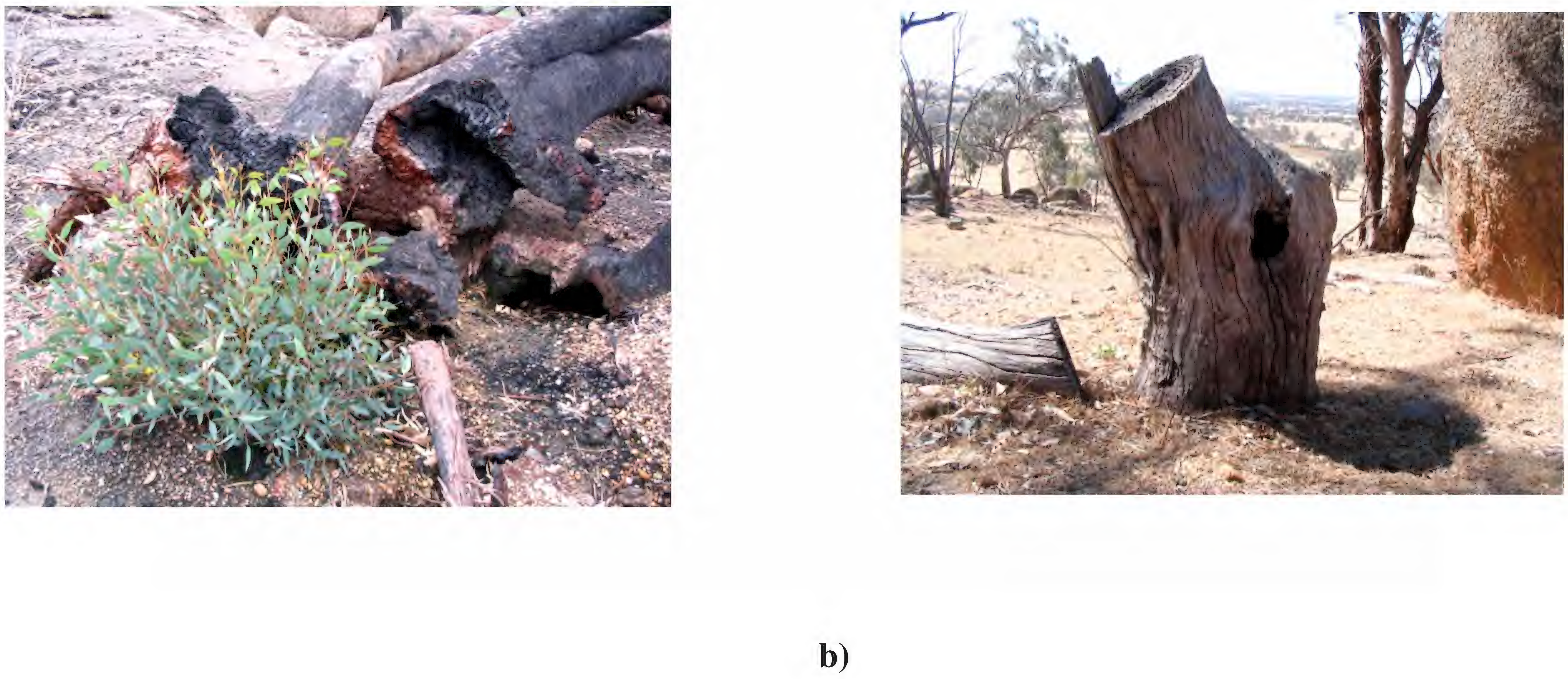
**a)**
**b)**

**Fig. 7.** Images showing **a)** basal regeneration of *Eucalyptus blakelyi* following a wildfire on a granite outcrop near Gerogery in 2008, and **b)** tree stump as evidence of past logging activities (Photos DM).

### *Environmental and agricultural weeds*

Exotic plants have become naturalized on granite outcrops around the world and are considered a major problem in preserving the integrity of inselberg flora (Porembski 2000). Exotic species can alter vegetation structure and fire regimes (Benwell 2007) and cause the extinction of endemic taxa (Pigott 2000). In this study 40% of the plants recorded were exotic, mostly agricultural species from the Poaceae and Asteraceae families (Appendix 1). However, had we conducted multiple surveys during different times of the year, the actual number of exotic species is predicted to be higher (Burrows 1999).

An interesting outcome of this study was the relationship between outcrop physical complexity, and a high number of native species but low number of exotic species (Figure 2). Structurally complex outcrops may support more native species because of the greater breadth of microhabitats available serving as refugia from livestock grazing. However, other factors such as fire history and the distance to roads, homesteads and towns, may also influence which invasive plants are likely to be present. Several 'woody weed' species recorded in this study have the potential to cause serious concern because they are long-lived, able to survive harsh conditions, and spread prolifically when mature (Low 1999). These species which include **Ailanthus altissima*, **Celtis australis*, **Lycium ferocissimum*, **Opuntia stricta*, **Prunus* spp., **Robinia pseudoacacia* and **Schinus areira* can be controlled and should be managed before they become a costly environmental problem. Several native species not local to the SWS including *Melia azedarach* were also recorded.

### *Floristic composition*

A key finding of this study was that floristic composition between outcrops was significantly dissimilar, with the majority of outcrops sharing less than 30% of total species, and less than 40% of native species (Figure 6). This result appears to be characteristic of granite outcrops in general. For example, Norris & Thomas (1991) found several granite outcrops in the SWS were floristically dissimilar. Furthermore, patterns of floristic diversity on granite outcrops in Western Australia are characterized by high diversity within homogenous habitats ($\alpha$-diversity), high species turnover along environmental gradients ($\beta$-diversity) and high species turnover among similar habitats across geographical gradients ($\gamma$-diversity) (Hopper 1992, Hopper et al. 1996). Our findings suggests that small granite outcrops in modified landscapes also conform to general patterns of floristic diversity, and highlights the need to protect a broad range of outcrops to maintain floristic diversity on a regional scale, by fencing out livestock and controlling feral animals such as goats, deer and rabbits.

### *Management Implications*

Traditional revegetation programs focus on stabilizing creek banks, mitigating dry land salinity by planting hill tops, creating wind breaks for livestock, and establishing wildlife corridors (Munroe & Lindenmayer 2011). In most cases, these efforts fail to incorporate rocky outcrops and consequently, many outcrops remain devoid of overstorey vegetation. In the SWS, many outcrops are less than 10 ha in size and occur as habitat isolates embedded within highly modified, cleared landscapes. This enhanced insularity has implications for the long-term persistence of saxicolous plant populations, especially for species with few individuals and which do not occur on the intervening parts of the landscape (Broadhurst & Young 2006). Our study has identified tor landforms to be severely degraded and in immediate need of restoration. Broadhurst et al. (2008) suggest introducing germplasm from genetically diverse source populations is required to increase the long-term viability of small plant populations in fragmented landscapes. This principle is applicable to outcrops in the SWS as they support small populations of several shrub species and small trees (Appendix 1). However ecological constrains such as grazing may be limiting some species, and landforms which support moderate amounts of remnant vegetation, such as koppies and nubbins, may benefit most from fencing to keep out livestock and feral herbivores, and to encourage natural regeneration.

Two findings of this study relevant to the design of restoration programs were the presence of shrubs and small trees, and the low density of large mature trees on structurally complex outcrops. The composition and structure of woodland vegetation may have important implications for the survival of rock-dwelling taxa. A recent study in the SWS bioregion for example found high densities of overstorey regrowth vegetation produced high shade levels and supported lower reptile diversity than structurally open outcrops (Michael et al. 2008). Dense vegetative regrowth may also affect growing conditions for saxicolous plants by competing for light and space, and altering micro-climatic conditions (Benwell 2007). Choosing appropriate plant species and carefully considering the density and spatial arrangement of plantings are fundamental issues in the design of future restoration programs involving outcrops.

## Conclusion

We examined vegetation structure and floristic composition of relatively small (< 11 ha) granite outcrops in modified landscapes. Tor landforms were most degraded and were characterized by a significant absence of canopy cover, midstorey species, shrubs and native ground cover. Tor landforms could therefore provide nodal points in the design of future restoration activities, which will need to consider appropriate plant species, the spatial arrangement of plantings and genetic diversity of seed stock. Overall, the high percentage of floristic dissimilarity among outcrops in this study highlights the need to manage a broad spectrum of outcrops to maintain floristic diversity in the SWS bioregion. In many cases, this may only require fencing out livestock, controlling invasive plants, monitoring outcomes and adjusting management according to site-specific objectives.

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## References

Ashton, D.H. & Webb, R.N. (1977) The ecology of granite outcrops at Wilson's Promontory, Victoria. *Australian Journal of Ecology* 2: 269–296.

Beadle, N.C.W. (1981) *The vegetation of Australia.* (Cambridge University Press: New York).

Benson, J.S. (2008) New South Wales vegetation classification and assessment: part 2 plant communities of the NSW South-western Slopes bioregion and update of the NSW Western Plains plant communities, version 2 of the NSWVCA database. *Cunninghamia* 10: 599–673.

Benwell, A. (2007) Response of rock-outcrop and fringing vegetation to disturbance by fire and drought. *Australian Journal of Botany* 55: 736–748.

Bradstock R.A., Williams J.E. and Gill M. (2002) *Flammable Australia: The fire regimes and biodiversity of a continent.* (Cambridge University Press: UK).

Broadhurst, L.M. and Young, A.G. (2006) Reproductive constraints for the long-term persistence of fragmented *Acacia dealbata* (Mimosaceae) populations in southeast Australia. *Biological Conservation* 133: 512–526.

Broadhurst, L.M., Young, A.G. and Forrester, R. (2008) Genetic and demographic responses of fragmented *Acacia dealbata* (Mimosaceae) populations in southeast Australia. *Biological Conservation* 141: 2843–2856.

Burgman, M.A. (1987) An analysis of the distribution of plants on granite outcrops in southern-western Australia using Mantel tests. *Vegetatio* 71: 79–86.

Burke, A. (2003) Inselbergs in a changing world – global trends. *Diversity and Distributions* 9: 375–383.

Burrows, G. (1999) A survey of 25 remnant vegetation sites in the South Western Slopes, New South Wales. *Cunninghamia* 6(2): 283–299.

Burrows, G. (2001) An assessment of the conservation status of *Senecio garlandii*, in the Central and South Western Slopes, New South Wales. *Cunninghamia* 7(1): 65–76.

Burrows, G. (2004) The importance of seasonality in the timing of flora surveys in the South and Central Western Slopes of New South Wales. *Cunninghamia* 8(4): 514–520.

Butler, D.W. & Fensham, R.J. (2008) Lose the plot: cost-effective survey of the Peak Range, central Queensland. *Cunninghamia* 10: 521–538.

Campbell, E.M. (1997) Granite landforms. *Journal of the Royal Society of Western Australia* 80: 101–112.

Clarke P.J. (2002) Habitat islands in fire-prone vegetation: do landscape features influence community composition? *Journal of Biogeography* 29: 1–8.

Clarke K.R. & Gorley R.N. (2006) *PRIMER v6* (Plymouth Marine Laboratory).

Gill, A.M. (1981) Adaptive responses of Australian vascular plant species to fires. In: Gill. A.M., Groves, R.H. & Noble, I.R. (eds) *Fire and the Australian biota*, pp 243–271 (National Academy of Science: Canberra).

Harden, G.J. (1990 – 2002) *Flora of New South Wales*. Vols I–IV (University of New South Wales Press: Sydney).

Hobbs, R.J. & Yates, C.J. (2000) *Temperate eucalypt woodlands in Australia*. (Surrey Beatty and Sons, Chipping Norton: Australia).

Hopper , S.D. (1992) Patterns of plant diversity at the population and species levels in south-west Australian Mediterranean ecosystems. In: Hobbs, R.J. (ed) *Biodiversity of Mediterranean ecosystems in Australia*, pp. 27–46. (Surrey Beatty & Sons, Chipping Norton: UK).

Hopper, S.D., Harvey, M.S., Chappill, J.A., Main, A.R. & Main, B.Y. (1996) The Western Australian Biota as Gondwanan heritage – a review. In Hopper, S.D., Chappil, J.A., Harvey, M.S. & George, A.S. (eds) *Gondwanan heritage*, pp. 1–46. (Surrey Beatty & Sons, Chipping Norton: UK).

Hopper, S.D., Brown, A.P. & Marchant, N.G. (1997) Plants of Western Australian granite outcrops. *Journal of the Royal Society of Western Australia* 80: 141–158.

Hunter, J.T. and Clarke, P.J. (1998) The vegetation of granitic outcrop communities on the New England Batholith of eastern Australia. *Cunninghamia* 5: 547– 618.

Keith D. A. (1996) Fire-driven extinction of plant populations: a synthesis of theory and review of evidence from Australian vegetation. *Proceedings of the Linnean Society of New South Wales* 116: 37–78.

Kruckenburg, A.R. (2002) *Geology and plant life: The effects of landforms and rock type on plants*. (University of Washington Press: USA).

Lindenmayer, D.B., Archer, S., Barton, P., Bond, S., Crane, M., Gibbons, P., Kay, G., MacGregor, C., Manning, A., Michael D.R., Montague-Drake, R., Munroe, N., Muntz, R. and Stagoll, K. (2011) *What makes a good farm for wildlife?* (CSIRO Publishing, Collingwood: Melbourne).

Low, T. (1999) *Feral Future*. (Viking: Australia).

Noble J.C. (2001) Lignotubers and meristem dependence in mallee (*Eucalyptus* spp.) coppicing after fire. *Australian Journal of Botany* 49: 31–41.

Michael, D.R., Cunningham, R.B. & Lindenmayer, D.B. (2008) A forgotten habitat? Granite inselbergs conserve reptile diversity in fragmented agricultural landscapes in south-eastern Australia. *Journal of Applied Ecology* 45: 1742–52.

Michael, D.R., Cunningham, R.B. & Lindenmayer, D.B. (2010a) Microhabitat relationships among five lizard species associated with granite outcrops in fragmented agricultural landscapes of South-eastern Australia. *Austral Ecology* 35: 214–225

Michael, D.R., Lindenmayer, D.B. & Cunningham, R.B. (2010b) Managing rock outcrops to improve biodiversity conservation in Australian agricultural landscapes. *Ecological Management and Restoration* 11: 43–50.

Munroe, N. & Lindenmayer, D.B. (2011) *Planting for wildlife: A practical guide to restoring native woodlands.* (CSIRO Publishing, Collingwood: Melbourne).

Murray Catchment Management Authority (2011) *Murray Catchment Management Authority Incentive Funding Program* (Murray Catchment Management Authority: Albury).

Norris, E.H. & Thomas, J. (1991) Vegetation on rocky outcrops and ranges in central and south-western New South Wales. *Cunninghamia* 2: 411–441.

Ohlemuller, R. (1997) *Biodiversity patterns of plant communities in shallow depressions on Western Australian granite outcrops (inselbergs)* (Diplomarbeit zur Erlangung des Grades eines Diplom-Biologen, University of Bonn: Bonn).

Ornduff, R. (1987) *Islands on islands: plant life on the granite outcrops of Western Australia* (University of Hawaii Press: Honolulu).

Packham G.H. & Day A.A. (1969) The general features of the geological provinces of

New South Wales. *Journal of the Geological Society of Australia* 16: 1–17.

Pigott, J. P. (2000) Environmental weeds and granite outcrops: possible solutions in the "too hard basket"? *Journal of the Royal Society of Western Australia* 83: 135–137.

Prober, S. (1996) Conservation of the grassy white box woodlands: range wide floristic variation and implications for reserve design. *Australian Journal of Botany* 44: 57–77.

Porembski, S. (2000) The invasibility of tropical granite outcrops ('inselbergs') by exotic weeds. *Journal of the Royal Society of Western Australia* 83: 131–137.

Porembski, S. & Barthlott, W. (2000) *Inselbergs: biotic diversity of isolated rock outcrops in tropical and temperate regions* (Ecological Studies 146, Springer-Verlag: Berlin).

Porembski, S., Seine, R. and Barthlott, W. (1997) Inselberg vegetation and the biodiversity of granite outcrops. *Journal of the Royal Society of Western Australia* 80: 193–199.

Smith, G.G. (1961) The flora of granite rocks of the Porongurup Range, south-western Australia. *Journal of the Royal Society of Western Australia* 45: 18–23.

Twidale, C.R. (1982) *Granite landforms* (Elsevier: Amsterdam).

Walters, T.W. (1982) The vascular flora of granite outcrops in the Central Mineral Region of Texas. *Bulletin of the Torrey Botanical Club* 109: 344–364.

Wildy, D.T., Bartle, J.R., Pate, J.S., Arthur, D.J. (2000) Sapling and coppice biomass production by alley-farmed 'oil mallee' *Eucalyptus* species in the Western Australian wheatbelt. *Australian Forestry* 63: 147–157.

Yates, C. & Hobbs, R. (1997) Temperate eucalypt woodlands: a review of their status, processes threatening their persistence and techniques for restoration. *Australian Journal of Botany* 45: 949–973.

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## Appendix 1. Native and exotic plant species recorded on four granite landforms in the South-west Slopes of NSW between October 2006 and February 2007 showing percentage frequency on each landform.

* = introduced species, # = noxious species, + = species listed in the NSW Threatened Species Conservation Act 1995).

| | **Nubbin** | **Koppie** | **Tors** | **Bornhardt** |
|---|---|---|---|---|
| **No of sites** | **13** | **8** | **17** | **6** |
| PTERIDOPHYTES | | | | |
| **Adiantaceae** | | | | |
| *Adiantum aethiopicum* | 23 | 0 | 0 | 0 |
| *Cheilanthes austrotenuifolia* | 62 | 75 | 59 | 50 |
| *Cheilanthes distans* | 8 | 0 | 24 | 0 |
| *Cheilanthes sieberi* | 23 | 25 | 29 | 33 |
| **Aspleniaceae** | | | | |
| *Asplenium flabellifolium* | 23 | 38 | 0 | 0 |
| *Pleurosorus rutifolius* | 31 | 75 | 41 | 67 |
| GYMNOSPERMS | | | | |
| **Cupressaceae** | | | | |
| *Callitris endlicheri* | 8 | 0 | 0 | 17 |
| *Callitris glaucophylla* | 31 | 0 | 6 | 33 |
| ANGIOSPERMS | | | | |
| **Amygdalaceae** | | | | |
| *Prunus dulcis** | 0 | 0 | 0 | 17 |
| *Prunus cerasifera** | 0 | 0 | 6 | 0 |
| **Anacardiaceae** | | | | |
| *Schinus areira** | 23 | 0 | 6 | 67 |
| **Anthericaceae** | | | | |
| *Arthropodium minus* | 15 | 0 | 6 | 0 |
| *Dichopogon fimbriatus* | 0 | 0 | 0 | 17 |
| *Tricoryne elatior* | 8 | 13 | 12 | 0 |
| **Apiaceae** | | | | |
| *Daucus glochidiatus* | 8 | 0 | 0 | 0 |
| *Hydrocotyle laxiflora* | 0 | 0 | 6 | 0 |

| | **Nubbin** | **Koppie** | **Tors** | **Bornhardt** |
|---|---|---|---|---|
| **No of sites** | **13** | **8** | **17** | **6** |
| **Asteraceae** | | | | |
| *Arctotheca calendula** | 23 | 25 | 47 | 50 |
| *Bidens pilosa** | 0 | 0 | 6 | 0 |
| *Carduus tenuiflorus** | 8 | 25 | 6 | 17 |
| *Carthamus lanatus** | 23 | 25 | 24 | 17 |
| *Cassinia aculeata* | 8 | 0 | 0 | 0 |
| *Cassinia laevis* | 8 | 0 | 0 | 0 |
| *Cassinia longifolia* | 15 | 0 | 0 | 0 |
| *Centaurea calcitrapa** | 8 | 0 | 0 | 0 |
| *Cichorium intybus** | 8 | 0 | 0 | 0 |
| *Cirsium vulgare** | 38 | 25 | 35 | 0 |
| *Conyza sumatrensis** | 0 | 0 | 0 | 17 |
| *Conyza bonariensis** | 0 | 0 | 6 | 0 |
| *Cynara cardunculus*#* | 0 | 13 | 0 | 0 |
| *Helichrysum rutidolepis* | 0 | 0 | 6 | 0 |
| *Hypochaeris glabra** | 31 | 25 | 35 | 17 |
| *Hypochaeris radicata** | 38 | 25 | 59 | 33 |
| *Lactuca serriola** | 0 | 0 | 12 | 0 |
| *Onopordum acanthium** | 8 | 0 | 6 | 0 |
| *Silybum marianum** | 8 | 13 | 0 | 0 |
| *Senecio garlandii+* | 0 | 13 | 0 | 17 |
| *Senecio hispidulus* | 8 | 0 | 0 | 33 |
| *Senecio quadritentatus* | 8 | 13 | 0 | 17 |
| *Sonchus asper** | 0 | 0 | 24 | 0 |
| *Sonchus oleraceus** | 0 | 0 | 12 | 0 |
| *Taraxacum officinale** | 15 | 13 | 12 | 0 |
| *Vittadinia cuneata* | 15 | 0 | 0 | 0 |
| *Xanthium spinosum*#* | 8 | 13 | 6 | 0 |
| *Xerochrysum viscosum* | 15 | 0 | 0 | 17 |
| **Boraginaceae** | | | | |
| *Echium plantagineum** | 23 | 88 | 65 | 33 |
| *Heliotropium europaeum** | 0 | 0 | 6 | 0 |
| **Cactaceae** | | | | |
| *Opuntia stricta*#* | 0 | 0 | 0 | 17 |
| **Campanulaceae** | | | | |
| *Wahlenbergia communis* | 0 | 0 | 6 | 0 |
| *Wahlenbergia stricta* | 0 | 0 | 6 | 0 |
| *Wahlenbergia gracilenta* | 23 | 13 | 24 | 17 |
| **Caryophyllaceae** | | | | |
| *Cerastium glomeratum** | 0 | 13 | 6 | 17 |
| *Moenchia erecta** | 8 | 0 | 0 | 0 |
| *Spergularia rubra** | 8 | 0 | 0 | 0 |
| *Stellaria media** | 15 | 13 | 0 | 0 |
| **Casuarinaceae** | | | | |
| *Allocasuarina verticillata* | 23 | 25 | 6 | 33 |
| **Chenopodiaceae** | | | | |
| *Dysphania pumilio* | 46 | 0 | 18 | 0 |
| *Einadia nutans* | 0 | 13 | 6 | 0 |
| **Convolvulaceae** | | | | |
| *Convolvulus erubescens* | 8 | 13 | 12 | 0 |
| *Dichondra repens* | 0 | 13 | 18 | 0 |
| **Crassulaceae** | | | | |
| *Crassula decumbens* | 15 | 13 | 0 | 0 |
| **Cucurbitaceae** | | | | |
| *Citrullus colocynthis** | 23 | 38 | 0 | 0 |
| *Cucumis myriocarpus** | 15 | 13 | 24 | 0 |

| | **Nubbin** | **Koppie** | **Tors** | **Bornhardt** |
|---|---|---|---|---|
| **No of sites** | **13** | **8** | **17** | **6** |
| **Cyperaceae** | | | | |
| *Carex appressa* | 0 | 13 | 18 | 0 |
| *Lepidosperma laterale* | 0 | 0 | 12 | 0 |
| **Dilleniaceae** | | | | |
| *Hibbertia obtusifolia* | 23 | 25 | 12 | 0 |
| **Ericaceae** | | | | |
| *Brachyloma daphnoides* | 8 | 0 | 0 | 0 |
| *Lissanthe strigosa* | 23 | 0 | 0 | 0 |
| *Melichrus urceolatus* | 0 | 0 | 6 | 0 |
| **Fabaceae** | | | | |
| *Acacia buxifolia* | 8 | 13 | 0 | 0 |
| *Acacia rubida* | 8 | 38 | 12 | 17 |
| *Acacia implexa* | 54 | 100 | 41 | 50 |
| *Acacia genistifolia* | 8 | 0 | 0 | 0 |
| *Acacia penninervis* | 0 | 13 | 6 | 17 |
| *Acacia doratoxylon* | 15 | 0 | 0 | 33 |
| *Desmodium varians* | 8 | 0 | 6 | 0 |
| *Glycine clandestina* | 8 | 25 | 12 | 0 |
| *Glycine tabacina* | 15 | 13 | 6 | 0 |
| *Hardenbergia violacea* | 15 | 0 | 0 | 0 |
| *Indigofera adesmiifolia* | 0 | 13 | 0 | 0 |
| *Indigofera australis* | 23 | 25 | 6 | 17 |
| *Pultenaea cunninghamii* | 0 | 13 | 0 | 17 |
| *Pultenaea platyphylla* | 0 | 13 | 6 | 0 |
| *Pultenaea foliolosa* | 8 | 0 | 0 | 0 |
| *Robinia pseudoacacia** | 8 | 0 | 0 | 0 |
| *Trifolium sp** | 8 | 38 | 18 | 0 |
| **Gentianaceae** | | | | |
| *Centaurium erythraea** | 8 | 0 | 0 | 0 |
| **Geraniaceae** | | | | |
| *Erodium cicutarium** | 0 | 0 | 24 | 17 |
| *Geranium retrorsum* | 0 | 13 | 0 | 0 |
| *Geranium solanderi* | 15 | 13 | 24 | 17 |
| *Pelagonium australe* | 15 | 13 | 12 | 0 |
| **Goodeniaceae** | | | | |
| *Goodenia pinnatifida* | 8 | 0 | 0 | 0 |
| **Haloragaceae** | | | | |
| *Gonocarpus elatus* | 54 | 0 | 0 | 0 |
| *Gonocarpus tetragynus* | 31 | 13 | 0 | 50 |
| **Hypericaceae** | | | | |
| *Hypericum perforatum** | 31 | 50 | 0 | 33 |
| **Iridaceae** | | | | |
| *Romulea rosea** | 8 | 0 | 18 | 0 |
| **Juncaceae** | | | | |
| *Juncus filicaulis* | 0 | 25 | 0 | 0 |
| **Lamiaceae** | | | | |
| *Ajuga australis* | 8 | 13 | 0 | 17 |
| *Marrubium vulgare** | 38 | 25 | 35 | 0 |
| *Salvia verbenaca** | 0 | 13 | 6 | 0 |
| **Lobeliaceae** | | | | |
| *Isotoma axillaris* | 62 | 100 | 71 | 83 |
| **Loranthaceae** | | | | |
| *Amyema miquelii* | 8 | 13 | 0 | 0 |
| *Amyema miraculosum* | 8 | 25 | 0 | 0 |
| *Amyema pendulum* | 8 | 13 | 6 | 0 |

| | **Nubbin** | **Koppie** | **Tors** | **Bornhardt** |
|---|---|---|---|---|
| **No of sites** | **13** | **8** | **17** | **6** |
| *Muellerina eucalyptoides* | 0 | 0 | 6 | 0 |
| **Malvaceae** | | | | |
| *Malva parviflora** | 8 | 13 | 0 | 0 |
| **Martyniaceae** | | | | |
| *Ibicella lutea** | 0 | 0 | 6 | 0 |
| **Meliaceae** | | | | |
| *Melia azedarach* | 8 | 0 | 0 | 0 |
| **Mimosaceae** | | | | |
| *Acacia buxifolia* | 8 | 13 | 0 | 0 |
| *Acacia rubida* | 8 | 38 | 12 | 17 |
| *Acacia implexa* | 54 | 100 | 41 | 50 |
| *Acacia genistifolia* | 8 | 0 | 0 | 0 |
| *Acacia penninervis* | 0 | 13 | 6 | 17 |
| *Acacia doratoxylon* | 15 | 0 | 0 | 33 |
| **Myoporaceae** | | | | |
| *Myoporum montanum* | 0 | 0 | 0 | 17 |
| **Myrtaceae** | | | | |
| *Eucalyptus albens* | 38 | 75 | 59 | 50 |
| *Eucalyptus blakelyi* | 54 | 63 | 29 | 83 |
| *Eucalyptus dealbata* | 62 | 25 | 0 | 33 |
| *Eucalyptus goniocalyx* | 23 | 38 | 12 | 17 |
| *Eucalyptus macrorhyncha* | 23 | 50 | 6 | 33 |
| *Eucalyptus melliodora* | 0 | 0 | 0 | 17 |
| *Eucalyptus nortonii* | 15 | 38 | 6 | 0 |
| *Eucalyptus polyanthemos* | 0 | 0 | 0 | 17 |
| *Syzgium australe** | 0 | 0 | 6 | 0 |
| **Orobanchaceae** | | | | |
| *Orobanche minor** | 0 | 13 | 24 | 0 |
| **Oxalidaceae** | | | | |
| *Oxalis perennans* | 85 | 38 | 47 | 33 |
| **Papaveraceae** | | | | |
| *Papaver somniferum** | 0 | 13 | 0 | 0 |
| **Phormiaceae** | | | | |
| *Dianella longifolia* | 8 | 0 | 0 | 0 |
| *Dianella revoluta* | 8 | 25 | 6 | 33 |
| **Phytolaccaceae** | | | | |
| *Phytolacca octandra** | 8 | 38 | 18 | 17 |
| **Poaceae** | | | | |
| *Aira cupaniana** | 8 | 0 | 6 | 17 |
| *Anthoxanthum odoratum** | 0 | 0 | 6 | 0 |
| *Aristida behriana* | 8 | 38 | 18 | 17 |
| *Aristida ramosa* | 31 | 38 | 18 | 17 |
| *Austrodanthonia eriantha* | 31 | 13 | 18 | 17 |
| *Austrodanthonia caespitosa* | 31 | 63 | 59 | 33 |
| *Austrodanthonia setacea* | 0 | 0 | 0 | 17 |
| *Austrostipa aristiglumis* | 15 | 13 | 0 | 0 |
| *Austrostipa scabra ssp. scabra* | 31 | 50 | 24 | 33 |
| *Austrostipa scabra ssp. falcata* | 15 | 13 | 18 | 33 |
| *Austrostipa densiflora* | 8 | 0 | 6 | 33 |
| *Avena fatua** | 31 | 50 | 47 | 67 |
| *Bothriochloa macra* | 46 | 63 | 35 | 0 |
| *Briza maxima** | 46 | 38 | 12 | 33 |
| *Bromus diandrus** | 46 | 50 | 59 | 67 |
| *Bromus hordeaceus** | 23 | 38 | 35 | 17 |
| *Bromus rubens** | 8 | 0 | 0 | 0 |
| *Bromus unioloides** | 0 | 25 | 6 | 0 |

| | **Nubbin** | **Koppie** | **Tors** | **Bornhardt** |
|---|---|---|---|---|
| **No of sites** | **13** | **8** | **17** | **6** |
| *Chloris truncata* | 8 | 13 | 6 | 0 |
| *Cymbopogon refractus* | 8 | 0 | 6 | 0 |
| *Cynosurus echinatus** | 8 | 0 | 0 | 0 |
| *Cynodon dactylon* | 0 | 0 | 6 | 0 |
| *Dichelachne crinata* | 38 | 38 | 35 | 0 |
| *Eleusine tristachya** | 8 | 0 | 0 | 0 |
| *Elymus scaber* | 15 | 50 | 35 | 17 |
| *Holcus lanatus** | 0 | 0 | 6 | 0 |
| *Hordeum leporinum** | 62 | 38 | 82 | 33 |
| *Hyparrhenia hirta*#* | 0 | 13 | 6 | 0 |
| *Joycea pallida* | 0 | 0 | 6 | 0 |
| *Lamarckia aurea** | 15 | 0 | 0 | 0 |
| *Lolium perenne** | 15 | 25 | 24 | 33 |
| *Microlaena stipoides* | 8 | 0 | 24 | 0 |
| *Panicum effusum* | 8 | 13 | 12 | 0 |
| *Paspalum dialatum** | 8 | 0 | 6 | 17 |
| *Phalaris aquatica** | 0 | 13 | 18 | 0 |
| *Phalaris paradoxa** | 0 | 0 | 6 | 0 |
| *Poa sieberi* | 15 | 13 | 6 | 0 |
| *Poa annua** | 0 | 0 | 6 | 0 |
| *Setaria verticillata** | 0 | 0 | 6 | 0 |
| *Themeda australis* | 0 | 0 | 6 | 0 |
| *Vulpia bromoides** | 0 | 13 | 18 | 0 |
| *Vulpia myuros** | 38 | 38 | 35 | 50 |
| **Polygonaceae** | | | | |
| *Acetosella vulgaris** | 46 | 100 | 71 | 17 |
| *Rumex brownii* | 38 | 38 | 47 | 0 |
| **Portulacaceae** | | | | |
| *Portulaca oleracea* | 0 | 0 | 6 | 0 |
| **Proteaceae** | | | | |
| *Grevillea floribunda* | 0 | 0 | 0 | 17 |
| **Rosaceae** | | | | |
| *Rosa rubiginosa** | 0 | 0 | 12 | 0 |
| *Rubus fruticosus** | 0 | 38 | 12 | 17 |
| **Rubiaceae** | | | | |
| *Galium aparine** | 0 | 0 | 0 | 17 |
| *Galium gaudichaudii* | 8 | 0 | 0 | 0 |
| **Rutaceae** | | | | |
| *Correa glabra* | 8 | 0 | 0 | 0 |
| *Correa reflexa* | 0 | 13 | 0 | 0 |
| **Santalaceae** | | | | |
| *Exocarpus cupressiformis* | 23 | 63 | 0 | 33 |
| *Santalum apiculatum* | 8 | 13 | 0 | 0 |
| **Sapindaceae** | | | | |
| *Dodonea viscosa* | 8 | 13 | 0 | 17 |
| **Scrophulariaceae** | | | | |
| *Verbascum virgatum** | 8 | 75 | 29 | 17 |
| **Simaroubaceae** | | | | |
| *Ailanthus altissima** | 0 | 0 | 18 | 17 |
| **Solanaceae** | | | | |
| *Lycium ferocissimum** | 8 | 0 | 0 | 17 |
| *Solanum cinereum* | 0 | 13 | 6 | 0 |
| *Solanum elaeagnifolium** | 15 | 0 | 0 | 0 |
| *Solanum nigra** | 8 | 38 | 53 | 33 |
| *Solanum simile* | 0 | 0 | 0 | 17 |

| | **Nubbin** | **Koppie** | **Tors** | **Bornhardt** |
|---|---|---|---|---|
| **No of sites** | **13** | **8** | **17** | **6** |
| **Sterculiaceae** | | | | |
| *Brachychiton populneus* | 62 | 63 | 41 | 17 |
| **Thymelaeaceae** | | | | |
| *Pimelea linifolia* | 15 | 13 | 0 | 0 |
| **Ulmaceae** | | | | |
| *Celtis australis** | 8 | 13 | 0 | 0 |
| **Urticaceae** | | | | |
| *Urtica urens** | 0 | 13 | 6 | 0 |
| **Viscaceae** | | | | |
| *Notothixos cornifolius* | 0 | 25 | 6 | 0 |
| **Xanthorrhoeaceae** | | | | |
| *Lomandra filiformis* | 23 | 25 | 35 | 0 |
| *Lomandra longifolia* | 0 | 25 | 6 | 0 |
| *Lomandra multiflora* | 15 | 13 | 0 | 17 |
| **Zygophyllaceae** | | | | |
| *Tribulus occidentalis* | 8 | 0 | 6 | 0 |

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# The conservation reserve system in the South Coast Region of NSW looks impressive, but does it adequately conserve threatened plant species?

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***Abstract*:** The listed threatened plant taxa within the South Coast Region of New South Wales (Helensburgh to Batemans Bay, as designated by the NSW National Parks and Wildlife Service) are documented. Of the 100 NSW listed taxa, 69 are also listed by the Commonwealth, while two additional taxa are only listed by the Commonwealth. An analysis of the individual taxa and the 62 conservation reserves in the region, found that 30 taxa can with confidence be said to be adequately reserved, while 50 are assessed as inadequately reserved; for the remaining 22 taxa, reservation status is unknown.

Examples of challenges for the conservation of threatened plants in the region are examined; these challenges have relevance well beyond the South Coast Region. Managing for individual plant species may be hampered by a lack of basic ecological information; this is particularly so for the rarer species such as orchids. One of the main areas where information is lacking is the response of most species to bushfire. Conservation on private land is becoming an increasingly important and challenging area for plant species conservation as the last large areas of public land are dedicated for one purpose or another. A more co-ordinated approach to conservation on private land may produce improved outcomes for many inadequately reserved taxa.

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## Introduction

During the past 15 years conservation areas on the NSW South Coast Region (as defined by the NSW National Parks and Wildlife Service – NPWS) have been greatly increased; these reservations have brought the area under NPWS management to 25 percent of the Region. There is a further 6,312 hectares in the Commonwealth Booderee National Park. This high proportion of conservation land reflects the fact that historically, a large part of the Region has remained undeveloped and unfarmed because of the poor soils associated with its extensive sandstone landscapes; it is at the southern end of the very extensive Sydney Basin geological province. Because the poor soils and rugged landscapes were of little value for agriculture, the majority of the sandstone country remained in public ownership with its native vegetation relatively undisturbed and suitable for subsequent reservation as conservation lands. This scenario is characteristic of most of the reserves in the Sydney Basin including much of the land which makes up the Greater Blue Mountains World Heritage Area for example. A consequence of this phenomenon is that the vast majority of the protected areas in the South Coast region are located on sandstone soils, and that sandstone landscapes and their characteristic vegetation are over-represented within the conservation reserve system. In contrast the more fertile country, with

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its substantially different suite of vegetation, is mostly in freehold ownership, much of it has been cleared and is poorly represented in reserves.

Land managed by NSW Forests covers a large part of the south-eastern part of the Region, and while much of that land is managed for wood production, conservation needs are considered in forestry operations. Forestry land, and other public land, is not investigated in this paper but this does not discount the importance of some of that land for the conservation of threatened plants.

With 62 reserves covering over 354,500 hectares, the reserve system in the South Coast Region looks impressive, but does it adequately conserve the threatened plant species occurring within the Region? This paper provides a contemporary review of the currently listed threatened plant species occurring in the Region and their conservation status. Challenges for the conservation of threatened plants in the Region are explored using first hand examples from the South Coast; these challenges are by no means unique to the South Coast Region.

### *The South Coast Region*

The South Coast Region, as considered in this paper, extends from Helensburgh in the north (just south of the metropolitan area of Sydney), to Batemans Bay in the south, and westwards to beyond Goulburn and the vicinity of Braidwood. The Region covers an area of 1.4 million hectares. Altitude ranges from sea level to over 1,100 metres on the peaks within Budawang National Park in the southwest corner of the region. Geology is highly variable. Sedimentary rocks of Permian and Triassic age within the Sydney Basin geological province cover the majority of the region, with extensive areas of Permian volcanic rocks (latite and volcanic sandstone) in the far northeast. The region overlaps the southern and south-western extremities of the Sydney Basin, so that on the tablelands in the west old sedimentary rocks of Ordovician and Devonian age occur with occasional igneous rocks. Tertiary basalt occurs in a few places, mainly at high altitudes. Annual average rainfall ranges from around 600 mm in the dry, western parts of the region to over 1,800 mm per year along the high escarpment in the far north.

Botanically, the Region overlaps the Central Coast, South Coast, Central Tablelands, and Southern Tablelands Botanical Subdivisions (PlantNET online, National Herbarium of NSW, Sydney). The Bio-Regions involved are the Sydney Basin, South-East Corner and South Eastern Highlands (NSW NPWS 2003). The Region primarily supports forests and woodlands, with extensive areas of heathland on sandstone landscapes (Mills & Jakeman 2010).

Broadly speaking, the region can be divided into three distinct areas; viz. (i) the coast and its hinterland, primarily supporting moist forests, (ii) the sandstone plateaux, supporting woodland and heathland and (iii) the tablelands, where modified woodlands and grasslands dominate, with forests in the wetter north-eastern corner on the Central Tablelands.

The total area covered by NPWS reserves in the Region is 348,192 hectares, contained within 61 protected areas. Parks Australia, a Commonwealth authority, manages Booderee National Park in the Jervis Bay Territory; that reserve covers 6,312 hectares. There are also two marine parks managed by Marine Parks Authority NSW. The terrestrial reserves represent over 25 percent of the total land area in the Region. These reserves range from three hectares in Belowla Island Nature Reserve to Morton National Park that covers 199,744 hectares; the latter park, one of the largest in NSW, represents 57% of the total reserved land in the Region. Of approximately 280 kilometres of coastline, 36 percent is managed by the NPWS or Parks Australia (Mills 2006).

Sixteen of the reserves (26%) are less than 100 hectares in area; this includes five oceanic island reserves. All protected areas in the Region are listed in Table 4, where the area of each reserve and other information is provided.

## Methods

Records of threatened plant species were sought from various places, most particularly:

- The Atlas of NSW Wildlife, maintained by the Office of Environment and Heritage (OEH), containing 4,192 records of threatened plant species within the South Coast Region;
- Threatened species information on the OEH web site;
- Information from staff and the library at the NPWS office in Nowra;
- Plans of management for the protected areas;
- The author's knowledge and library of information on the flora of the region.

All threatened taxa records in the Region were assessed to identify the occurrence of taxa within protected areas; all obviously erroneous records were excluded and outdated taxonomy corrected. Information on population numbers was more difficult to obtain, as detailed field surveys are lacking for the majority of species. Statements about reservation status were only made where firm population information was available.

Each species is assessed for 'reservation adequacy'. The assessment, determined by the author and made largely on a subjective basis, with some quantitative information for some species, indicates the adequacy or otherwise of each species within the reserve system of the NSW NPWS South Coast Region. The terms used are: adequate – substantial populations occur within one or more protected areas or all/almost all known populations occur in protected areas; inadequate – substantial populations do not occur in a protected area or most known populations are outside the reserve system, although small numbers may be reserved; and unknown – the adequacy of reservation could not be determined because of a lack of information.

**Table 1. Number of Listed Plant Taxa in the South Coast Region**

| | TSC Act | | EPBC Act | | EPBC only |
|---|---|---|---|---|---|
| extinct | 1 | 1% | 1 | 1% | - |
| critically endangered | 4 | 4% | 2 | 3% | - |
| endangered | 50 | 50% | 24 | 35% | 1 |
| vulnerable | 45 | 45% | 42 | 61% | 1 |
| All listed species | 100 | 100% | 69 | 100% | 2 |

**Table 2. Growth Habit of Listed Taxa**
(Note. Figures are also the approximate percentage)

| Usual growth habit | Number |
|---|---|
| Tree | 6 |
| Mallee | 3 |
| Shrub | 54 |
| Vine | 1 |
| Forb | 15 |
| Grass | 2 |
| Sedge | 2 |
| Orchid | 16 |
| Fern | 3 |
| All species | 102 |

**Table 3. General habitat showing number of Listed taxa**
(Note. Figures are also the approximate percentage)

| General Habitat Category | Number |
|---|---|
| Rainforest/moist eucalypt forest | 10 |
| Forest | 24 |
| Woodland/heathland (sandstone) | 32 |
| Swamps (sandstone) | 5 |
| Woodland/scrub (tablelands) | 14 |
| Grassy woodland/grassland | 6 |
| Upland peat swamps | 6 |
| Estuarine wetlands/sandy beaches | 5 |

## The Threatened Species in the South Coast Region

Threatened plant taxa in NSW as listed under the *Threatened Species Conservation Act 1995* are continually being added to through determinations made by the NSW Scientific Committee (as provided for under the Act). Species can also be listed under the *Fisheries Management Act 1994*, although no plant species have yet been listed for the Region under that Act. As of March 2012, 637 plant taxa are listed as threatened in NSW; 100 (15.6%) occur within the South Coast Region, which covers 1.7% of the state.

The threatened plant taxa occurring within the South Coast Region are summarised in Table 5. The table provides information on plant families, taxonomic and common names for each taxon, their status under the above act and in the South Coast Region, the regional protected area(s) in which the taxon is known to occur, habitat, growth habit and reservation status as determined in this paper. Those taxa listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) are identified and their status indicated. Two species are listed only by the Commonwealth; these species are included in this analysis.

### *Status*

102 plant taxa occurring in the Region are listed as extinct, critically endangered, endangered or vulnerable under the TSC Act and/or the EPBC Act (Table 1).

As far as is known, there is only one plant species that has apparently become extinct in this region; this is the orchid *Arachnorchis cadyi* (*Caladenia cadyi*); see Stephenson (2011). This species is not listed as extinct under either the TSC Act or EPBC Act, even though there is provision to list species that are presumed extinct. The taxon *Amperea xiphoclada* var. *pedicellata* is listed under both acts as extinct, although there have been recent records from several parts of the Region (Atlas of NSW Wildlife, March 2012). Of the 102 species listed for the region, 69 (69%) are listed under the Commonwealth EPBC Act.

### *Endemism and limit of distribution*

Regional endemism is high; 33% of the listed species occur nowhere else except the South Coast Region, or have almost all of their known populations within this region. Endemism is particularly high among the orchids; nine of the 16 listed species are found only in the Region.

The number of taxa at their southern limit of geographic distribution is also high, 39%; the number of taxa at their northern limit in the Region is lower at 14%. A total of 86% of all listed taxa are either endemic or at their limit of distribution, demonstrating the high importance of the region for plant conservation. The high percentage of "southern limit species" is partly explained by the fact that the Region overlaps the southern edge of the Sydney Basin; there is a major change in the flora to the south of the Basin, from just north of Batemans Bay.

### *Growth habit*

The listed species range from small herbs to large trees (Table 2). Growth habit is important because, among other things, it reflects the detectability of the species, an issue that is further discussed below. Woody plants, readily detectable perennial species, account for 65 (65%) of the listed taxa. The remainder are mostly far less easily detected, this is particularly so for the orchids because they flower for only a short period each year, if at all.

### *Habitat*

The taxa listed occur in a wide range of habitats within the Region (Table 5). The greatest number of species, about 40%, are found on sandstone landscapes, including forests, woodlands, heathlands and swamps. Even though the Region contains very extensive areas of forest habitat, this is not reflected in the number of threatened species found in forest.

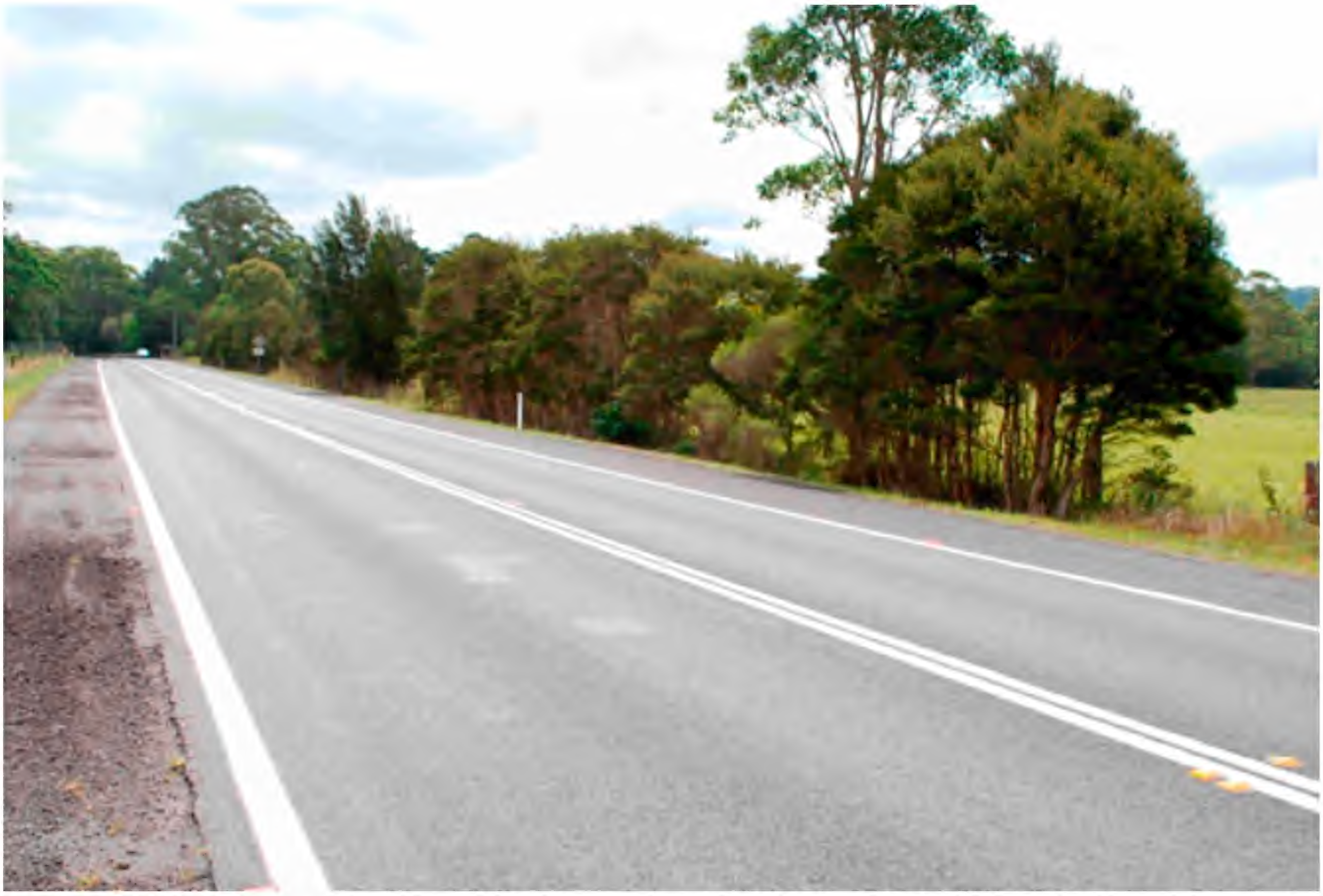

**Fig. 1.** The threatened tree *Melaleuca biconvexa* beside the Princes Highway at Wandandian. This species is not well represented within protected areas.

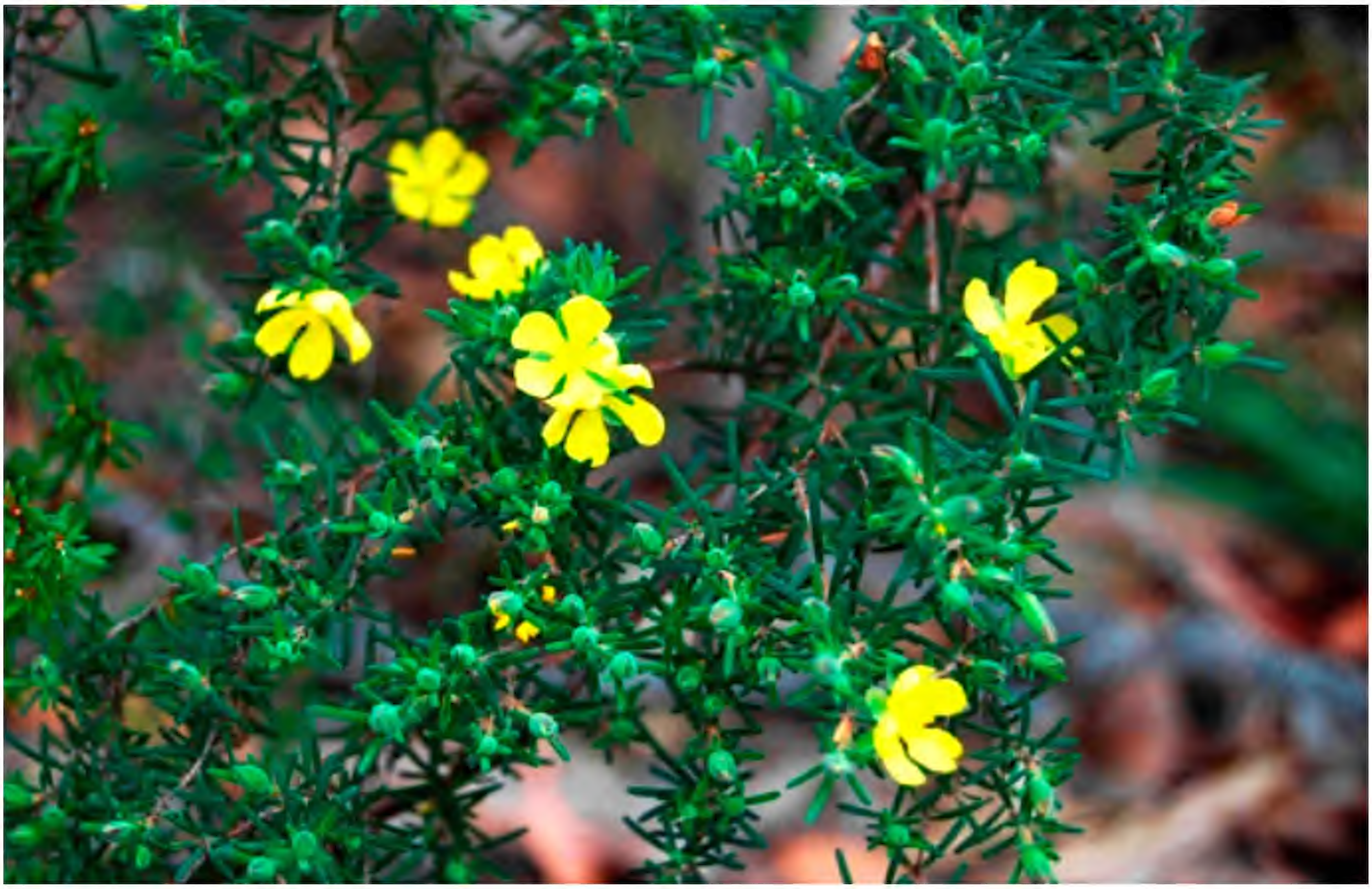

**Fig. 2.** *Hibbertia stricta* subsp. *furcatula*; recently found to be very common to the west of Nowra on the South Coast, particularly within Colymea SCA.

### *Adequacy of reservation*

Analysis of all 102 taxa indicates that 30 species are adequately reserved, 50 species are inadequate and adequacy for 22 species is unknown.

Among other things, the above figures indicate that much information is lacking in terms of our knowledge of the distribution and abundance of listed species. Although only an estimate, the fact that 50 percent of the listed taxa are identified as inadequately reserved is of concern. With such a high percentage of the land area of the region reserved, one may ask why this figure is so high. The answer is partly that the majority of inadequately reserved taxa occur in those areas where modified landscapes and private land dominates; i.e. in the coastal zone and on the tablelands. Lack of information on which species occur within which reserves is also a contributing factor. Most of the taxa associated with sandstone landscapes are considered to be adequately reserved.

### *Conservation challenges*

The following regional examples demonstrate some of the challenges surrounding the conservation of threatened plants on the South Coast, and cover problems associated with surveying, reserving and managing listed taxa in the Region, as well as issues associated with rapidly changing information on individual species. The issues raised are by no means unique to this region.

### *Difficulty of survey*

There are about 130 terrestrial orchids in the South Coast Region, including some undescribed taxa; 16 are currently listed as threatened. These plants flower once per year for a short period, if at all, and most cannot be confidently identified without flowers. Additionally, accurate identification of some taxa requires expert knowledge. For these reasons, assessing the potential impacts of developments or activities on listed orchids is particularly problematic. Habitat assessment can play an important role in such assessments (e.g. the work of Clark et al. 2004 on *Cryptostylis hunteriana*), but is not definitive. This is because of a lack of information on the preferred habitat, particularly for the rare species, and many species may occur in several habitats. Although the presence of orchid species in the Region is known, large sections of the reserve system and elsewhere remain inadequately surveyed for them. The known distribution and abundance of many species will ultimately change over the coming years; taxonomic revisions will also modify our view of this group in the Region.

Other small plants can often be difficult to locate in surveys. *Galium australe*, for example, is problematical, because it is small and easily overlooked, occurs in very scattered and small populations, and records of the taxon are often erroneous because of taxonomic confusion and misidentification.

### *Difficulty of reservation*

*Melaleuca biconvexa* (Figure 1) is a tree growing in moist coastal places from Port Macquarie on the North Coast, south to Jervis Bay on the South Coast, where the species is quite localised, occurring from about Currambene Creek south to Wandandian, a distance of about 15 kilometres. Within that area populations are primarily found along drainage lines and on swampy ground, amongst developed land (almost entirely on private land), and very difficult to reserve within NPWS protected areas. Despite the key areas where it grows being on land zoned for environmental protection, or on large private holdings where development is unlikely, the species is threatened by infrastructure development and maintenance, pollution, weeds and clearing by land owners.

### *Change in reservation status*

The reservation status of a species can change very quickly; this may occur as a result of inclusion within a newly gazetted protected area, or as a result of field surveys that record new populations within existing reserves.

The endemic mallee *Eucalyptus langleyi* occurs in a limited area to the west of Nowra, where there are 37 known populations containing many thousands of plants spread through the woodland and heathland on the Nowra Sandstone (Mills 2010). Prior to 2001 the species was unknown in a protected area, but a major dedication of Crown Land as conservation reserves in early 2001, particularly Colymea State Conservation Area, Parma Creek Nature Reserve and Jerrawangala National Park, protected nearly all known populations. Consequently the conservation status changed from highly inadequately reserved to almost completely reserved.

### *Change in knowledge*

Information on the distribution of a species can change greatly through field survey; such is the case with *Hibbertia stricta* subsp. *furcatula,* (previously known as *Hibbertia sp. nov*. (Menai) (Figure 2). When the taxon was first listed in 2007 it was known from a few collections in Sutherland Shire on the southern outskirts of Sydney, and a handful of collections from near Nowra on the South Coast (NSW Scientific Committee 2007). At the time the Committee stated "the *South Coast* metapopulation is less well known [than the Sutherland metapopulation], but herbarium specimen records show it occurring just to the west and south-west of Nowra, with most of the six collections made prior to 1970."

Field studies by Mills (2009) found that this shrub is abundant within Colymea State Conservation Area, west of Nowra, and further searches by the author found populations in Bomaderry Creek Regional Park and Parma Creek Nature Reserve, near Nowra. The species must now be considered adequately reserved on the south coast. These findings also suggest that there is evidence that the taxon should be reclassified as vulnerable, rather than endangered.

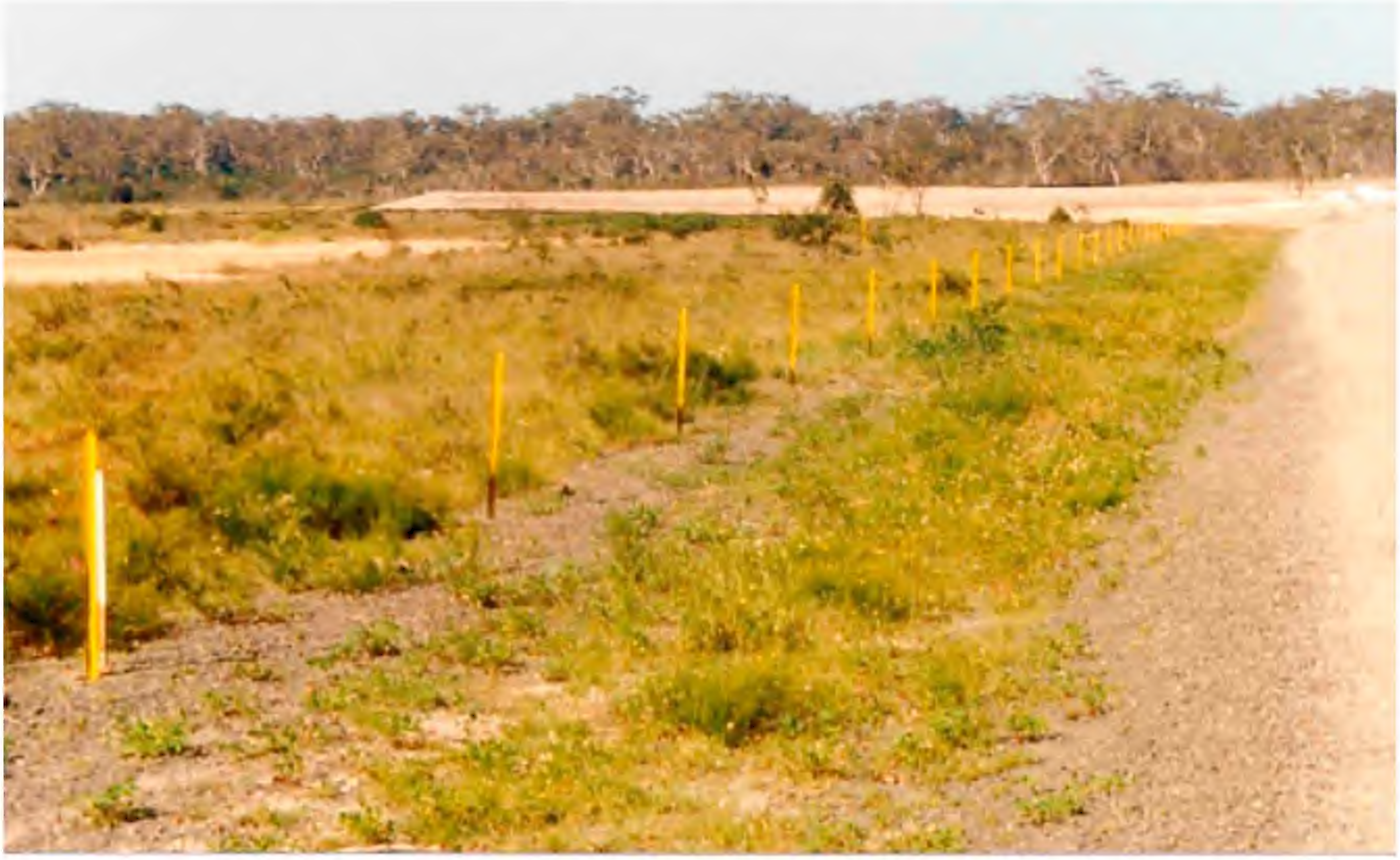

**Fig. 3.** *Prasophyllum affine* site at Vincentia in November 2000.

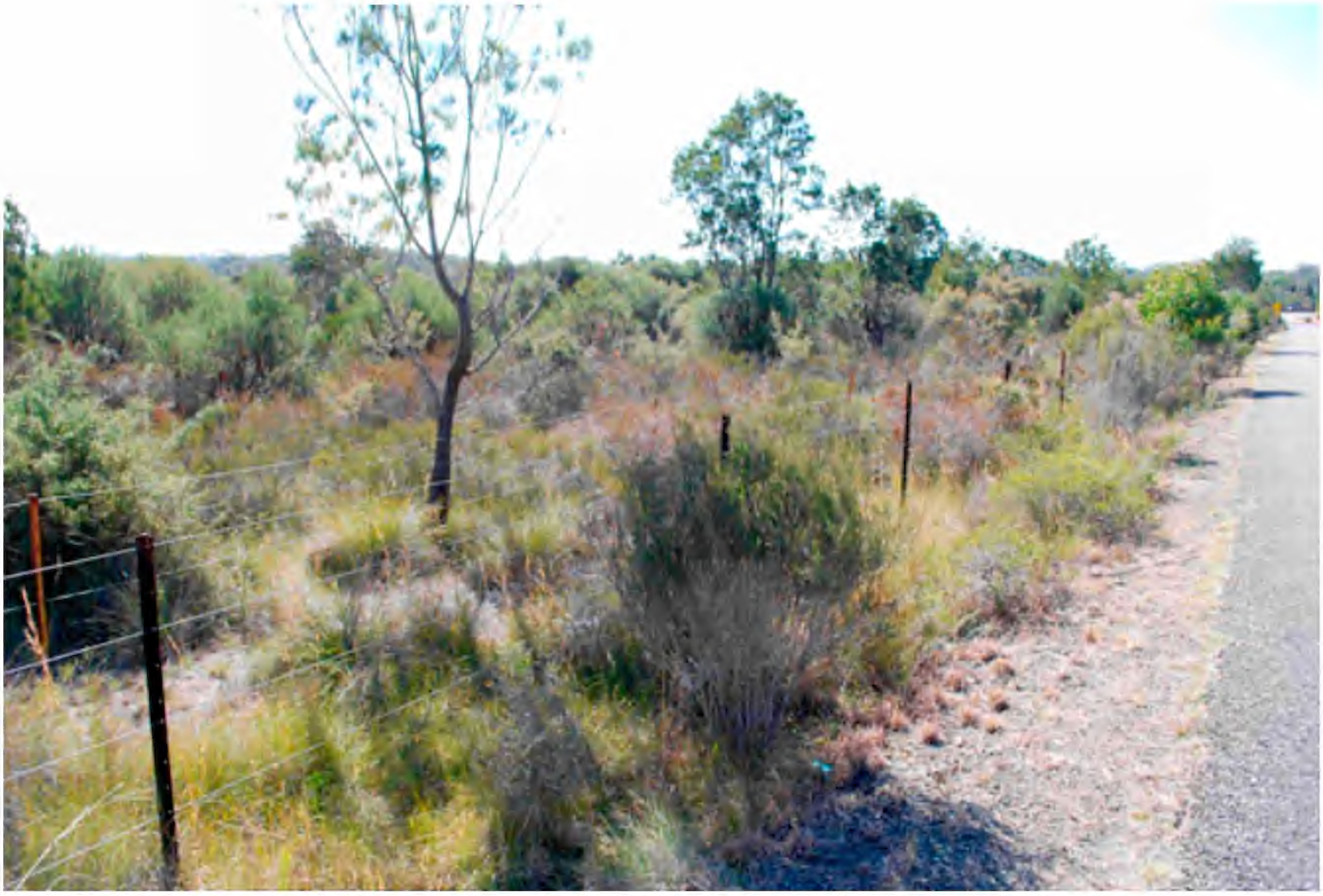

**Fig. 4.** *Prasophyllum affine* site at Vincentia in August 2012; taken from same location as in Figure 3.

**Table 4. Alphabetical list of protected areas in the NSW NPWS South Coast Region showing size and number of threatened species**

1. To nearest hectare. 2. Species listed under the NSW *Threatened Species Conservation Act 1995* and documented in Table 5. 3. CC – Central Coast; CT – Central Tablelands; SC – South Coast; ST – Southern Tablelands. 4. SB – Sydney Basin; SEC – South-East Corner; SEH – South-Eastern Highlands.

| NPWS Reserves | Area (hectares)[1] | No. TSCA species[2] | Botanical Subdivision[3] | Bio-Region[4] |
|---|---|---|---|---|
| 1. Back Arm NR | 92 | 0 | CT | SEH |
| 2. Bamarang NR | 374 | 1 | SC | SB |
| 3. Bangadilly NP | 2137 | 1 | CT | SB |
| 4. Barren Grounds NR | 2090 | 1 | CT | SB |
| 5. Barrengarry NR | 21 | 0 | SC | SB |
| 6. Bees Nest NR | 1541 | 1 | ST | SEH |
| 7. Belowla Island NR | 3 | 0 | SC | SB |
| 8. Berkeley NR | 9 | 2 | CC | SB |
| 9. Bimberamala National Park | 4420 | 0 | SC | SEC |
| 10. Bomaderry Creek Regional Park | 85 | 4 | CC | SB |
| 11. Brundee Swamp NR | 227 | 0 | SC | SB |
| 12. Brush Island NR | 37 | 0 | SC | SB |
| 13. Budawang NP | 23819 | 5 | ST | SEH.SB |
| 14. Budderoo NP | 7217 | 12 | CT | SB |
| 15. Bugong NP | 1011 | 0 | CC | SB |
| 16. Bungonia NP | 770 | 3 | ST | SEH |
| 17. Bungonia State Conservation Area | 3285 | 4 | ST | SEH |
| 18. Cambewarra Range NR | 1681 | 4 | CC | SB |
| 19. Cecil Hoskins NR | 47 | 1 | CT | SB |
| 20. Clyde River NP | 1263 | 0 | SC | SEC |
| 21. Colymea SCA | 1674 | 5 | SC | SB |
| 22. Comerong Island NR | 714 | 0 | SC | SB |
| 23. Conjola NP | 11599 | 5 | SC | SB |
| 24. Cookbundoon NR | 539 | 0 | ST | SEH |
| 25. Corramy RP | 291 | 1 | SC | SB |
| 26. Cullendulla Creek NR | 127 | 0 | SC | SEC |
| 27. Cullunghutti AA | 66 | 0 | CC | SB |
| 28. Dharawal NR | 376 | 1 | CC | SB |
| 29. Dharawal SCA | 6685 | 6 | CC | SB |
| 30. Five Islands NR | 278 | 0 | CC | SB |
| 31. Illawarra Escarpment SCA | 2635 | 5 | CC | SB |
| 32. Jerralong NR | 334 | 0 | ST | SEH |
| 33. Jerrawangala NP | 4031 | 4 | SC | SB |
| 34. Jervis Bay NP | 5248 | 9 | SC | SB |
| 35. Kangaroo River NR | 118 | 0 | CC | SB |
| 36. Kerrawary NR | 366 | 0 | ST | SEH |
| 37. Macquarie Pass NP | 1062 | 2 | CC | SB |
| 38. Macquarie Pass SCA | 166 | 0 | CC | SB |
| 39. Meroo NP | 3846 | 3 | SC | SB |
| 40. Morton NP | 199744 | 32 | SC.CT.ST | SB. SEH |
| 41. Morton SCA | 1028 | 0 | SC | SB |
| 42. Murramarang Aboriginal Area | 60 | 0 | SC | SB |
| 43. Murramarang NP | 12367 | 3 | SC | SB |
| 44. Nadgigomar NR | 3868 | 4 | ST | SEH |
| 45. Narrangarril NR | 105 | 0 | ST | SEH |
| 46. Narrawallee Creek NR | 872 | 0 | SC | SB |
| 47. Parma Creek NR | 3643 | 2 | SC | SB |
| 48. Pomaderris NR | 100 | 1 | ST | SEH |
| 49. Robertson NR | 5 | 0 | CT | SB |
| 50. Rodway NR | 85 | 0 | SC | SB |
| 51. Saltwater Swamp NR | 214 | 0 | SC | SB |
| 52. Seven Mile Beach NP | 953 | 1 | CC | SB |
| 53. Tapitallee NR | 94 | 0 | CC | SB |
| 54. Tarlo River NP | 8211 | 3 | ST | SEH |
| 55. Tollgate Islands NR | 11 | 0 | SC | SEC |
| 56. Triplarina NR | 151 | 3 | CC | SB |
| 57. Upper Nepean SCA | 25268 | 7 | CC | SB |
| 58. Wogamia NR | 278 | 0 | SC | SB |
| 59. Woollamia NR | 453 | 1 | SC | SB |
| 60. Worrigee NR | 615 | 1 | SC | SB |
| 61. Yatteyattah NR | 35 | 0 | SC | SB |
| Region total reserved NPWS land | 348,193 ha | | | |
| **Parks Australia Reserve (Jervis Bay Territory)** | | | | |
| 62. Booderee National Park | 6,312 ha | 1 | SC | SB |

### *Unexpected Discoveries*

Much of the Region is botanically under-explored, at least in terms of its detail, and botanical forays into the wilderness areas regularly turn up unexpected finds. Two such finds were recently made by the author in the sandstone country west of Nowra, neither of which were very far from public access tracks. The shrub *Hakea dohertyi* was previously known only from a small area in the Blue Mountains, until it was found in the Shoalhaven about 77 km further south, in a different botanical subdivision (Mills 2008). The question arose as to whether the occurrence was natural or whether seeds had been transported from the Blue Mountains to the South Coast site by a 4WD vehicle.

The shrub *Zieria murphyi* occurs on the Central Tablelands, in the Blue Mountains and in the Penrose-Bundanoon area. The author came across populations of this species on the South Coast about 50 km south of the closest known occurrence at Penrose. There is no doubt that many other such discoveries are yet to be made in the remote and not so remote parts of the region. Every new discovery modifies and enhances our knowledge of the threatened species in the Region.

### *Species in highly modified environments*

The problem of conserving rare species in highly modified environments in not new. The major reason for species decline in these areas is habitat loss and disturbance, along with competition from weeds; such species may not have originally been rare. Several species associated with the Permian volcanics in the Shellharbour – Kiama area have suffered greatly from the extensive clearing of the subtropical rainforest and associated vegetation in that district; these species include *Zieria granulata*, *Daphnandra johnsonii* and *Cynanchum elegans*. These species are now restricted to remnants and regrowth vegetation across their former limited range; occurrences are largely on private land. The first two species are endemic to the region and are of high priority for conservation efforts but reserving the habitat of these species is very difficult because of the highly fragmented nature of the remnants.

### *Manipulating habitat for threatened species*

Plant populations are not stable over time, as habitat change in response to environmental conditions, fire, geomorphic influences and growth of vegetation is inevitable. Habitat change may be beneficial to some species but detrimental to others. Generally, disturbance will be beneficial to short-lived "pioneer" species, while being detrimental to long-lived species. Fire is the omnipotent force in Australian vegetation dynamics and may be a key determinant of vegetation structure and species composition; fire ecology is a large subject on its own and will not be further discussed here.

Habitat manipulation is sometimes necessary to maintain a population of a rare species. For example the orchid *Prasophyllum affine* is endemic to the Jervis Bay district and is known only from a handful of discrete sites. The largest population is at Vincentia, where the natural habitat is sedge-heathland. Since the population was discovered in 2000, shrubs and trees have invaded the area such that within a short time the whole area will support dense woody vegetation; see Figures 3 and 4. This terrestrial orchid is unlikely to tolerate a dense shrub cover so is likely to be lost from the site unless the woody plants are removed. Because of surrounding developments, wildfire is now unlikely so that intervention to modify the habitat, i.e. to remove shrub and tree cover, is required to manage the site for the orchid's survival.

### *Unnatural occurrences*

The tree *Syzygium paniculatum* grows primarily in littoral rainforest; it occurs north from Lake Conjola on the South Coast to Bulahdelah on the North Coast. This is now a commonly grown garden plant and has been planted extensively within its natural range and well outside of it along the coast. Where specimens are found in its usual natural coastal habitat the question arises whether it is a natural population or whether it has originated from a planted tree in the vicinity of the occurrence. If originating from planted specimens, what is its conservation value? Does it have the same legal protection as a natural occurrence? The dilemma of planted individuals of threatened species is not addressed in the Final Determination from the NSW Scientific Committee listing this species, nor is it addressed for any other listed species that is used in cultivation. There is a concern about maintaining the genetic integrity of natural populations when specimens of unknown origin are planted nearby and may interbreed.

## Discussion

The listed threatened species occurring in the South Coast Region encompass a broad range of species in terms of growth habit, distribution, rarity and reservation status. The majority of the Region still supports natural vegetation so that some of the listed species are identified as threatened because they are naturally rare or have a highly restricted geographic distribution, rather than becoming threatened through habitat removal or other human activity; about 14 percent of the taxa are in this category. The conservation of most of the listed species relies upon appropriate management of the reserve system and other public land, including state forests, Crown land and council land.

The most important taxa in the Region are the endemic species, as they occur nowhere else in the wild. Of the 34 endemic/near endemic species, 12 (35%) are considered to be adequately reserved, while 20 (59%) are considered inadequately reserved. Possibly the most important is the endemic monotypic genus *Budawangia* (Ericaceae), a genus of only one species *Budawangia gnidioides*, almost entirely confined to Morton National Park (it is named from the Budawang Range), and is adequately reserved.

The priority for conservation effort should be directed towards those endemic taxa that occur outside the reserve system, particularly those occurring in highly modified environments

**Table 5. List of Threatened Plants for the NPWS South Coast Region**

Notes. 1. CE – critically endangered; E – endangered; V – vulnerable in NSW; X – presumed extinct. 2. Category: E – endemic to region or almost so. R – almost entirely occurring within protected areas. W – widespread but rare; S/N – at southern/northern limit of distribution in the region. 3. Reserve numbers are provided in Table 4; U – unknown due to taxonomic confusion. 4. Refers to status in the South Coast Region only. 5. Names for orchids in brackets are proposed but not yet widely accepted.

| **Family**<br>**Taxon** | **Common Name** | **Status[1]**<br>**TSC(EPBC)** | **Regional**<br>**Status[2]** | **Habit** | **Habitat** | **Reserve(s)[3]** | **Reservation[4]** |
|---|---|---|---|---|---|---|---|
| **Araliaceae** | | | | | | | |
| *Astrotricha crassifolia* | Thick-leaf Star-hair | V(V) | - | Shrub | Woodland (sandstone) | - | Unknown |
| **Asteraceae** | | | | | | | |
| *Leucochrysum albicans* var. *tricolor* | Hoary Sunray | -(E) | - | Herb | Grassy woodland | - | Inadequate |
| *Xerochrysum palustre* | Swamp Everlasting | -(V) | N | Herb | Peat swamp | - | Inadequate |
| **Apocynaceae** | | | | | | | |
| *Cynanchum elegans* | White Cynanchum | E(E) | S | Vine | Subtropical rainforest. | 8 | Inadequate |
| **Atherospermataceae** | | | | | | | |
| *Daphnandra johnsonii* | Illawarra Socketwood | E(E) | E | Tree | Subtropical rainforest | 14 | Inadequate |
| **Brassicaceae** | | | | | | | |
| *Irenepharsus trypherus* | Illawarra Irene | E(E) | E | Herb | Forest | 6,14,18,37,40 | Inadequate |
| **Convolvulaceae** | | | | | | | |
| *Wilsonia backhousei* | Wilsonia | V(-) | - | Herb | Estuarine foreshores | 24,34 | Adequate |
| *Wilsonia rotundifolia* | Round-leaved Wilsonia | E(-) | - | Herb | Estuarine foreshores | 24,34 | Adequate |
| **Cupressaceae** | | | | | | | |
| *Callitris oblonga* ssp. *corangensis* | Pygmy Cypress Pine | V(V) | E | Shrub | Riparian scrub/forest | 40 | Inadequate |
| **Cyperaceae** | | | | | | | |
| *Carex klaphakei* | Klaphake's Sedge | E(-) | S | Sedge | Swamps (sandstone) | - | Inadequate |
| **Dilleniaceae** | | | | | | | |
| *Hibbertia stricta* subsp. *furcatula* | Guinea Flower | E(-) | S | Shrub | Woodland/heathland (sandstone) | 10,21,47 | Adequate |
| **Dryopteridaceae** | | | | | | | |
| *Lastreopsis hispida* | Bristly Shield Fern | E(-) | - | Fern | Rainforest | - | Unknown |
| **Ericaceae** | | | | | | | |
| *Budawangia gnidioides* | Budawangs Cliff-heath | V(V) | E.R | Herb | Overhangs/caves (sandstone) | 40 | Adequate |
| *Epacris purpurascens* var. *purpurascens* | Heath | V(-) | S | Shrub | Woodland/heathland (sandstone) | 57 | Adequate |
| *Leucopogon exolasius* | Woronora Beard-heath | V(V) | E.R | Shrub | Gully forest, riparian sites | 29,57 | Adequate |
| **Euphorbiaceae** | | | | | | | |
| *Amperea xiphoclada* var. *pedicellata* | Amperea | X(X) | S | Shrub | Woodland, heath (sandstone) | 33,39,40,54,57 | Unknown |
| *Euphorbia psammogeton* | Sand Spurge | E(-) | S | Herb | Sandy beaches | 34,52 | Inadequate |
| **Fabaceae** | | | | | | | |
| **Caesalpinioideae (subfamily)** | | | | | | | |
| *Senna acclinis* | Rainforest Cassia | E(-) | S | Shrub | Rainforest/moist forest | - | Inadequate |
| **Faboideae (subfamily)** | | | | | | | |
| *Bossiaea bombayensis* | Bombay Bossiaea | V(-) | E | Shrub | Riparian scrub (tablelands) | - | Inadequate |
| *Bossiaea oligosperma* | Few-seeded Bossiaea | V(V) | S | Shrub | Woodland (tablelands) | - | Inadequate |
| *Dillwynia glaucula* | Michelago Parrot-pea | E(-) | N | Shrub | Woodland (tablelands) | 44 | Inadequate |
| *Phyllota humifusa* | Dwarf Phyllota | V(V) | E | Shrub | Woodland/heathland (deep sand) | 16 | Inadequate |
| *Pultenaea aristata* | Illawarra Bush-pea | V(V) | S | Shrub | Woodland/heathland (sandstone) | 28,29,31 | Adequate |
| *Pultenaea baeuerlenii* | Budawangs Bush-pea | V(V) | E,R | Shrub | Swamps (sandstone) | 13,40 | Adequate |
| *Pultenaea elusa* | Elusive Bush-pea | CE(E) | E | Shrub | Swamps (sandstone) | - | Inadequate |
| *Pultenaea pedunculata* | Matted Bush-pea | E(-) | - | Shrub | Woodland (tablelands) | 16,40 | Adequate |
| *Swainsona sericea* | Silky Swainson-pea | V(-) | - | Herb | Woodland, grassland | - | Inadequate |

| **Family** | | **Status[1]** | **Regional** | | | | |
|---|---|---|---|---|---|---|---|
| **Taxon** | **Common Name** | **TSC(EPBC)** | **Status[2]** | **Habit** | **Habitat** | **Reserve(s)[3]** | **Reservation[4]** |
| **Mimosoideae (subfamily)** | | | | | | | |
| *Acacia baueri* ssp. *aspera* | Wattle | V(-) | S | Shrub | Heathland (sandstone) | 29 | Unknown |
| *Acacia bynoeana* | Bynoe's Wattle | E(V) | S.R | Shrub | Woodland/heathland (sandstone) | 21,40,54 | Adequate |
| *Acacia flocktoniae* | Flockton Wattle | V(V) | S | Shrub | Forest (sandstone) | - | Unknown |
| *Acacia pubescens* | Downy Wattle | V(V) | S | Shrub | Forest | - | Inadequate |
| **Gentianaceae** | | | | | | | |
| *Gentiana wingecarribiensis* | Wingecarribee Gentian | E(E) | E | Herb | Upland peat swamps | - | Inadequate |
| **Geraniaceae** | | | | | | | |
| *Pelargonium striatellum* ms (Lake Bathurst) | Pelargonium | E(E) | N | Herb | Tableland lake edges | - | Inadequate |
| **Goodeniaceae** | | | | | | | |
| *Dampiera fusca* | Kydra Dampiera | E(-) | N | Herb | Heath, tablelands | 44 | Adequate |
| **Halogagaceae** | | | | | | | |
| *Haloragis exalata* ssp. *exalata* | Square Raspwort | V(V) | - | Shrub | Riparian scrub/forest | 8 | Inadequate |
| **Lamiaceae** | | | | | | | |
| *Prostanthera densa* | Villous Mint-bush | V(V) | S | Shrub | Woodland/heathland (sandstone) | 34,62 | Inadequate |
| **Malvaceae** | | | | | | | |
| *Rulingia prostrata* | Dwarf Kerrawang | E(E) | E | Shrub | Woodland (tablelands) | 44 | Unknown |
| **Myrtaceae** | | | | | | | |
| *Callistemon linearifolius* | Netted Bottle Brush | V(-) | - | Shrub | Dry forest | 40 | Inadequate |
| *Eucalyptus aggregata* | Black Gum | V(-) | - | Tree | Riparian woodland (tablelands) | 40 | Inadequate |
| *Eucalyptus aquatica* | Paddys River Swamp Gum | V(V) | E | Tree | Peat Swamps | 40 | Inadequate |
| *Eucalyptus langleyi* | Nowra Mallee Ash | V(V) | E | Mallee | Woodland/heathland (sandstone) | 10,21,33,47 | Adequate |
| *Eucalyptus macarthurii* | Paddys River Box | V(-) | S | Tree | Woodland (tablelands) | 3,19 | Inadequate |
| *Eucalyptus recurva* | Mongarlowe Mallee | E(E) | N | Mallee | Woodland/heathland (tablelands) | | - |
| *Eucalyptus sturgissiana* | Ettrema Mallee | V(-) | E | Mallee | Woodland/heathland (sandstone) | 33,40 | Adequate |
| *Kunzea cambagei* | Cambage's Kunzea | V(V) | S | Shrub | Scrub/heath (sandstone) | - | Adequate |
| *Leptospermum thompsonii* | Monga Tea Tree | V(V) | N | Shrub | Upland swamps (sandstone) | 13,40 | Adequate |
| *Melaleuca biconvexa* | Biconvex Paperbark | V(V) | S | Tree | Coastal swamps and watercourses | 25,34,59 | Inadequate |
| *Melaleuca deanei* | Deane's Paperbark | V(V) | S | Shrub | Woodland/heathland (sandstone) | 21,40,57 | Adequate |
| *Syzygium paniculatum* | Magenta Lilly Pilly | E(V) | S | Tree | Primarily littoral rainforest | 24,31,47,62 | Inadequate |
| *Triplarina nowraensis* | Nowra Heath-myrtle | E(E) | E | Shrub | Woodland/heathland (sandstone) | 2,56 | Adequate |
| **Orchidaceae[5]** | | | | | | | |
| *Caladenia tessellata (Arachnorchis tessellata)* | Thick Lip Spider Orchid | E(V) | W | Orchid | Woodland (sandstone) | 14,34 | Inadequate |
| *Calochilus pulchellus* | Pretty Beard Orchid | E(-) | E | Orchid | Heathland (sandstone) | - | Inadequate |
| *Cryptostylis hunteriana* | Leafless Tongue Orchid | V(V) | W | Orchid | Woodland/heathland (sandstone) | 18,24,33,34,39,40,43,56 | Unknown |
| *Diuris aequalis* | Buttercup Doubeltail | E(V) | - | Orchid | Grassy woodland (tablelands) | - | Inadequate |
| *Genoplesium baueri* | Bauer's Midge Orchid | V(-) | S | Orchid | Woodland (sandstone) | 10. | Inadequate |
| *Genoplesium plumosum* | Tallong Midge Orchid | E(E) | E | Orchid | Heathland (sandstone) | - | Inadequate |
| *Genoplesium superbum (Corunastylis superba)* | Midge Orchid | E(-) | S | Orchid | Woodland/heathland (sandstone) | 40 | Inadequate |
| *Genoplesium vernale (Corunastylis vernalis)* | East Lynne Midge Orchid | V(V) | N | Orchid | Forest | 40 | Inadequate |
| *Prasophyllum affine* | Jervis Bay Leek Orchid | E(E) | E | Orchid | Heathland (sandstone) | 34 | Inadequate |
| *Prasophyllum uroglossum* | Wingecarribee Leek Orchid | E(E) | E | Orchid | Peat swamps | - | Inadequate |
| *Pterostylis gibbosa (Oligochaetochilus gibbosus)* | Illawarra Greenhood | E(E) | E | Orchid | Forest | 60 | Inadequate |
| *Pterostylis pulchella (Diplodium pulchellum)* | Waterfall Greenhood | V(V) | S | Orchid | Woodland/heathland (sandstone) | 40 | Adequate |
| *Pterostylis ventricosa (Spectulantha ventricosa)* | Greenhood | CE(-) | E | Orchid | Woodland and forest | - | Inadequate |
| *Pterostylis vernalis (Spectulantha vernalis)* | Spring Tiny Greenhood | E(CE) | E | Orchid | Heathland, woodland (sandstone) | 56 | Inadequate |
| *Rhizanthella slateri* | Underground Orchid | V(E) | S | Orchid | Woodland (sandstone) | - | Inadequate |
| *Thelymitra* sp. (*kangaloonica*) | Kangaloon Sun Orchid | CE(CE) | E | Orchid | Swamps (sandstone) | 14 | Adequate |
| **Poaceae** | | | | | | | |
| *Distichlis distichophylla* | Australian Saltgrass | E(-) | N | Grass | Estuarine margins | 34 | Unknown |
| *Plinthanthesis rodwayi* | Budawangs Wallaby Grass | E(V) | E.R | Grass | Heathland (sandstone) | 13.40 | Adequate |

| Family<br>Taxon | Common Name | Status[1]<br>TSC(EPBC) | Regional<br>Status[2] | Habit | Habitat | Reserve(s)[3] | Reservation[4] |
|---|---|---|---|---|---|---|---|
| **Polygonaceae** | | | | | | | |
| *Persicaria elatior* | Tall Knotweed | V(V) | - | Herb | Riparian (freshwater) | - | Inadequate |
| **Polypodiaceae** | | | | | | | |
| *Grammitis stenophylla* | Narrow-leafed Finger Fern | E(-) | S | Fern | Rainforest | 40 | Unknown |
| **Primulaceae** | | | | | | | |
| *Lysimachia vulgaris* var. *davurica* | Yellow Loosestrife | E(-) | N | Herb | Upland peat swamps | - | Unknown |
| **Proteaceae** | | | | | | | |
| *Grevillea molyneuxii* | Wingello Grevillea | V(E) | E | Shrub | Woodland/heathland (sandstone) | 40 | Unknown |
| *Grevillea parviflora* ssp. *parviflora* | Grevillea | V(V) | S | Shrub | Forest to heath | 29,57 | Unknown |
| *Grevillea renwickiana* | Nerriga Grevillea | E(-) | E | Shrub | Woodland/heathland (tablelands) | 13,40 | Inadequate |
| *Grevillea rivularis* | Carrington Falls Grevillea | E(E) | E.R | Shrub | Riparian woodland (sandstone) | 14 | Adequate |
| *Hakea dohertyi* | Kowmung Hakea | E(E) | S | Shrub | Forest (sandstone) | - | Inadequate |
| *Persoonia acerosa* | Mossy Geebung | V(V) | S | Shrub | Woodland, heathland | - | Unknown |
| *Persoonia bargoensis* | Bargo Geebung | E(V) | S | Shrub | Forest/woodland (sandstone) | 57 | Unknown |
| *Persoonia glaucescens* | Mittagong Geebung | E(V) | S | Shrub | Woodland/forest (clayey soils) | 40,57 | Unknown |
| *Persoonia hirsuta* | Hairy Geebung | E(E) | S | Shrub | Woodland/heathland (sandstone) | 29 | Adequate |
| *Persoonia nutans* | Nodding Geebung | E(E) | S | Shrub | Woodland (sandstone) | - | Adequate |
| **Restionaceae** | | | | | | | |
| *Baloskion longipes* | Dense Cord-rush | V(V) | S | Sedge | Upland swamps/depressions | 13,40 | Unknown |
| **Rhamnaceae** | | | | | | | |
| *Pomaderris adnata* | Sublime Point Pomaderris | E(-) | E.R | Shrub | Forest on sandstone | 31 | Adequate |
| *Pomaderris cotoneaster* | Cotoneaster Pomaderris | E(E) | - | Shrub | Forest (tablelands) | 16,40 | Adequate |
| *Pomaderris delicata* | Delicate Pomaderris | CE(-) | E | Shrub | Forest (sandstone) | 48 | Inadequate |
| *Pomaderris pallida* | Pale Pomaderris | V(V) | N | Shrub | Forest (tablelands) | 44 | Unknown |
| *Pomaderris sericea* | Silky Pomaderris | E(V) | S | Shrub | Forest (sandstone) | 40 | Unknown |
| *Pomaderris walshii* | Carrington Falls Pomaderris | E(-) | E | Shrub | Riparian scrub/forest | 14 | Inadequate |
| **Rubiaceae** | | | | | | | |
| *Galium australe* | Tangled Bedstraw | E(-) | W.N | Herb | Forest to heathland | U | Unknown |
| **Rutaceae** | | | | | | | |
| *Boronia deanei* ssp. *acutifolia* | Deane's Boronia | V(V) | N.R | Shrub | Moist forest and heaths | 14,40 | Adequate |
| *Correa baeuerlenii* | Chef's Cap Correa | V(V) | N | Shrub | Riparian forests/rock outcrops | 40 | Unknown |
| *Zieria baeuerlenii* | Bomaderry Zieria | E(E) | E.R | Shrub | Dry forest (sandstone) | 10 | Adequate |
| *Zieria granulata* | Illawarra Zieria | E(E) | E | Shrub | Rock outcrops (volcanic) | 4,14 | Inadequate |
| *Zieria murphyi* | Velvet Zieria | V(V) | S | Shrub | Forest (sandstone) | 40 | Adequate |
| *Zieria* sp. Cambewarra | Zieria | V(V) | N | Shrub | Moist forest ? | - | Unknown |
| **Santalaceae** | | | | | | | |
| *Thesium australe* | Austral Toadflax | V(V) | W | Herb | Grassy woodland/grassland | - | Unknown |
| **Sapindaceae** | | | | | | | |
| *Dodonaea procumbens* | Creeping Hop-bush | V(V) | N | Shrub | Grassland/woodland (tablelands) | - | Inadequate |
| **Solanaceae** | | | | | | | |
| *Solanum celatum* | Night-shade | E(-) | E | Shrub | Moist forest to dry woodland | 14,17,18,31,37,40 | Inadequate |
| **Tectariaceae** | | | | | | | |
| *Arthropteris palisotii* | Lesser Creeping Fern | E(-) | S | Fern | Rainforest | 14,31 | Adequate |
| **Thymelaeaceae** | | | | | | | |
| *Pimelea axiflora* subsp. *pubescens* | Bungonia Rice-flower | E(-) | E.R | Shrub | Woodland/scrub (limestone) | 16,17 | Adequate |
| *Pimelea curviflora* var. *curviflora* | Rice-flower | V(V) | - | Shrub | Forest | - | Inadequate |
| *Pimelea spicata* | Rice-flower | E(E) | S | Shrub | Grassy woodland (clayey soils) | - | Inadequate |

or areas with current or likely future development pressure. Three areas that stand out in this regard are:

i) the Permian volcanics in the far northeast of the region, which include the endemics, *Cynanchum elegans* and *Zieria granulata*;

ii) the Nowra-Jervis Bay area, which has a high concentration of endemic species for example *Prasophyllum affine* and *Zieria baeuerlenii,* and is under much development pressure;

iii) the tablelands, where there are few reserves and listed species are widely dispersed across an often highly modified landscape, for example *Diuris aequalis* and *Eucalyptus aggregata*.

The reservation status of individual taxa varies from those that are wholly within the reserve system to those that are not represented in any reserve. Based on current knowledge, and some reasonable assumptions, only 30 % of the listed taxa are considered to be adequately reserved. Most of these occur on sandstone landscapes, where most of the reserves are located.

Adequately reserved does not always mean that a species is secure; reserve management is often critical to ensure long term viability. Fire management can manipulate habitat but there may be a balance between individual species needs (plants and animals) and the need for protection of humans and their assets. Activities within reserves, such as provision of visitor facilities and road maintenance may be detrimental to some species. Lack of ecological information on a species and its habitat, and the location of the species in the reserve are often problems in this regard.

Not surprisingly, there is a general positive relationship between reserve size and the number of listed taxa in the reserve, that is the larger the reserve the more taxa present. But the pattern is more complicated than this, and there do seem to be concentrations of listed species in certain districts (as noted above) so that reserves in those localities contain higher numbers of taxa. Small reserves can also contain a higher number of taxa than may be expected, while the extensive Budawang National Park contains fewer species than would perhaps be expected.

Some listed species occur on public land other than NPWS estate. These lands are not reserved for conservation as their primary purpose, nor are they subject to formal management regimes developed to conserve natural conservation values. However this is not to dismiss such land as unimportant for the conservation of threatened plants; many areas, including some small council reserves, contribute importantly to regional conservation efforts.

Managing highly localised taxa, whether in a reserve or not, poses a challenge as individual incidents can destroy or seriously deplete a population. This is nowhere more evident than in the case of orchids, where many of the listed species have very localised occurrences. A single development such as a road upgrade could potentially destroy most of the known population of very restricted species.

Recognition of the ecological requirements of individual taxa is also an important consideration for the land manager. As with the example of *Prasophyllum affine* above, not doing something may be just as detrimental as carrying out an activity. Other species, such as *Plinthanthesis rodwayi*, a grass endemic to the Budawang Ranges, and *Thesium australe*, a grassland species on the coast and tablelands, may also be negatively impacted by lack of disturbance and increasing shrub density. Disturbance is beneficial to some species; such disturbance may come from fire, natural geomorphic change or even unnatural modifications to vegetation and/or soil.

Managing highly dispersed small populations of a taxon, particularly within a highly modified landscape, is particularly problematic. The vine *Cynanchum elegans* grows in subtropical rainforest remnants and associated *Lantana* thickets in the largely cleared landscape between Wollongong and Kiama. Individual plants are usually found, separated by kilometres of grazing paddocks and developed land. Reservation of sites in such circumstances is difficult and the species is threatened by clearing of regrowth and *Lantana*, both able to be legally carried out as a routine agricultural practice. The long term viability of such small and isolated populations must be of concern.

This paper has dealt only with those taxa specifically listed under Commonwealth and State threatened species legislation. There are also nationally listed rare species, usually referred to as ROTAP species (Briggs & Leigh 1996), that warrant consideration in plant species conservation. The ROTAP list has no legislative significance and is dated, but is still useful in identifying those species considered to be rare. Although most of these are likely to be adequately reserved, climate change, development pressure and/or further field study may well see some of these species listed as threatened in the future.

## Conclusion

This paper has presented the current situation for listed threatened plants in the South Coast Region; it must be regarded as a “snapshot in time”. Further field studies will result in new listings of plants, and future new reservations of land for conservation purposes, albeit small in area, will inevitably occur. Other investigations will modify our understanding of the distribution and abundance of some species, including reservation status; various taxonomic changes will also occur.

Several key challenges for the conservation of threatened plants in the Region have been identified. Managing for individual plant species may be hampered by a lack of basic ecological information; this is particularly so for the rarer species such as orchids. One of the main areas where information is lacking is the response of most species to bushfire.

Conservation on private land is becoming an increasingly important and challenging area for plant species conservation as the last large areas of public land are dedicated for one purpose or another. Mechanisms are available for conservation on private land, including voluntary conservation agreements, and assistance through the Landrace program and catchment management authorities. A more co-ordinated approach to conservation on private land may produce improved outcomes for many inadequately reserved taxa.

Climate change and sea level rise are unknown challenges ahead. The tendency towards a more severe fire regime, i.e. more frequent and hotter fires, may pose the greatest threat to plant conservation. The predicted rise in sea level will affect beaches and estuaries; some of this change will be unpredictable, but a changing coastal environment is more likely than not.

## Acknowledgements

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## References

Commonwealth of Australia (1999). *Environment Protection and Biodiversity Conservation Act 1999*. Commonwealth Government, Canberra.

Briggs, J. & Leigh, J. (1996). *Rare or Threatened Australian Plants.* CSIRO, Canberra, 466pp.

Clark, S., deLacey, C. & Chamberlain, A. (2004). Using environmental variables and multivariate analysis to delineate preferred habitat for *Cryptostylis hunteriana,* the Leafless Tongue Orchid, in the Shoalhaven Local Government Area, NSW. *Cunninghamia* 8(4); 467–476.

Mills, K. (2006). The beach flora of the South Coast Region of New South Wales. *Illawarra Vegetation Studies*, 15. Coachwood Publishing, Jamberoo, April.

Mills, K. (2009). Investigation of the undescribed taxon *Hibbertia* sp. nov. 'Menai' (Dilleniaceae). Kevin Mills & Associates, Jamberoo, December.

Mills, K. (2008). Rare Plants of the Illawarra 3: The Endangered Shrub *Hakea dohertyi* (Proteaceae) in the Shoalhaven Region. *Illawarra Vegetation Studies* (17), Coachwood Publishing, Jamberoo, NSW, December.

Mills, K. (2010). Rare Plant Species in the Illawarra 4: *Eucalyptus langleyi* (Myrtaceae). *Illawarra Vegetation Studies* (20), Coachwood Publishing, Jamberoo, NSW.

Mills, K. & Jakeman, J. (2010). *Native Trees of the NSW South Coast*. Envirobooks, Canterbury, 246pp.

National Parks and Wildlife Service (NPWS) (2003). *The Bioregions of New South Wales: their biodiversity, conservation and history*. NSW National Parks and Wildlife Service, Hurstville.

New South Wales (1995). *Threatened Species Conservation Act 1995*. NSW Government, Sydney.

New South Wales (1994). *Fisheries Management Act 1994*. NSW Government, Sydney.

NSW Scientific Committee (2007). Final Determination: *Hibbertia sp.* nov. 'Menai' as an endangered species. The Committee, Hurstville, August.

Stephenson, A. W. (2011). *Orchid Species of the Shoalhaven*. The Author, Nowra, 54 pp.

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# The vegetation of the Mount Murchison and Wilga areas, Paroo Darling National Park, western New South Wales

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**Abstract:** The vegetation of the Mount Murchison and Wilga areas, Paroo Darling National Park (latitude 31°00'-32° 40'S and longitude 142°10'-144°25'E) in north western New South Wales was assessed using intensive quadrat sampling and mapped using extensive ground truthing and interpretation of aerial photograph and Landsat Thematic Mapper satellite images. In the survey 237 vascular plant species including 37 (15.6%) exotic species, from 46 families were recorded. Seventeen vegetation communities were identified and mapped, 15 for Mount Murchison area and 13 for the Wilga area. The most widespread for Mount Murchison being *Maireana pyramidata* low open shrubland, *Flindersia maculosa* low open woodland, *Muehlenbeckia florulenta* open shrubland and *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland. The most widespread for Wilga being *Muehlenbeckia florulenta* open shrubland and *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland. Many of these communities have been impacted by a history of 150 years of pastoral use.

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## Introduction

Paroo Darling National Park (latitude 31°00'-32 °40'S and longitude 142 °10'-144 °25'E) is located in north-western New South Wales, north-east of the town of Wilcannia (Fig. 1). The park was created in October 2002, incorporating the previously gazetted Peery National Park (created from three pastoral stations: Peery, Mandalay and Arrow Bar) with the addition of Coonavitra, Mount Murchison, Wilga and Tilpilly Stations. The Park now covers an area of approximately 221,000 hectares.

Paroo Darling National Park is made up of six separate areas (Fig 1). The pastoral stations Peery, Mandalay and Arrow Bar together make up the northern most area of the park known as the Peery Lake area (formerly Peery National Park). The Mount Murchison area and the Wilga area are separated by the Darling River. The Tillpilly area is the eastern most extent of the park situated between the Barrier Highway and the Wilcannia-Bourke Road. The Coonavitra area is south-east of these areas, consisting of blocks both north and south of the Barrier Highway.

Major features of the park are the Darling River that flows between the Mount Murchison and Wilga areas, Peery Lake which is a part of the Paroo Overflow, the rugged sandstone hills to the west of the lake, and the rugged Greenough Hill range of the Northern block of the Coonavitra area.

Detailed floristic survey and vegetation mapping has been completed for the Peery Lake area (Westbrooke *et al.* 2002; Westbrooke *et al.* 2003) and the Tilpilly area (Hunter & Fallavollita 2003). In June and November 2005 an intensive vegetation survey was conducted of the Wilga, Mount Murchison and Coonavitra blocks (Westbrooke *et al.* 2006a; Westbrooke *et al.* 2006b). The vegetation of the Coonavitra block is documented in Westbrooke *et al.* (2011), and this paper presents the results of the survey of the Mount Murchison and Wilga blocks.

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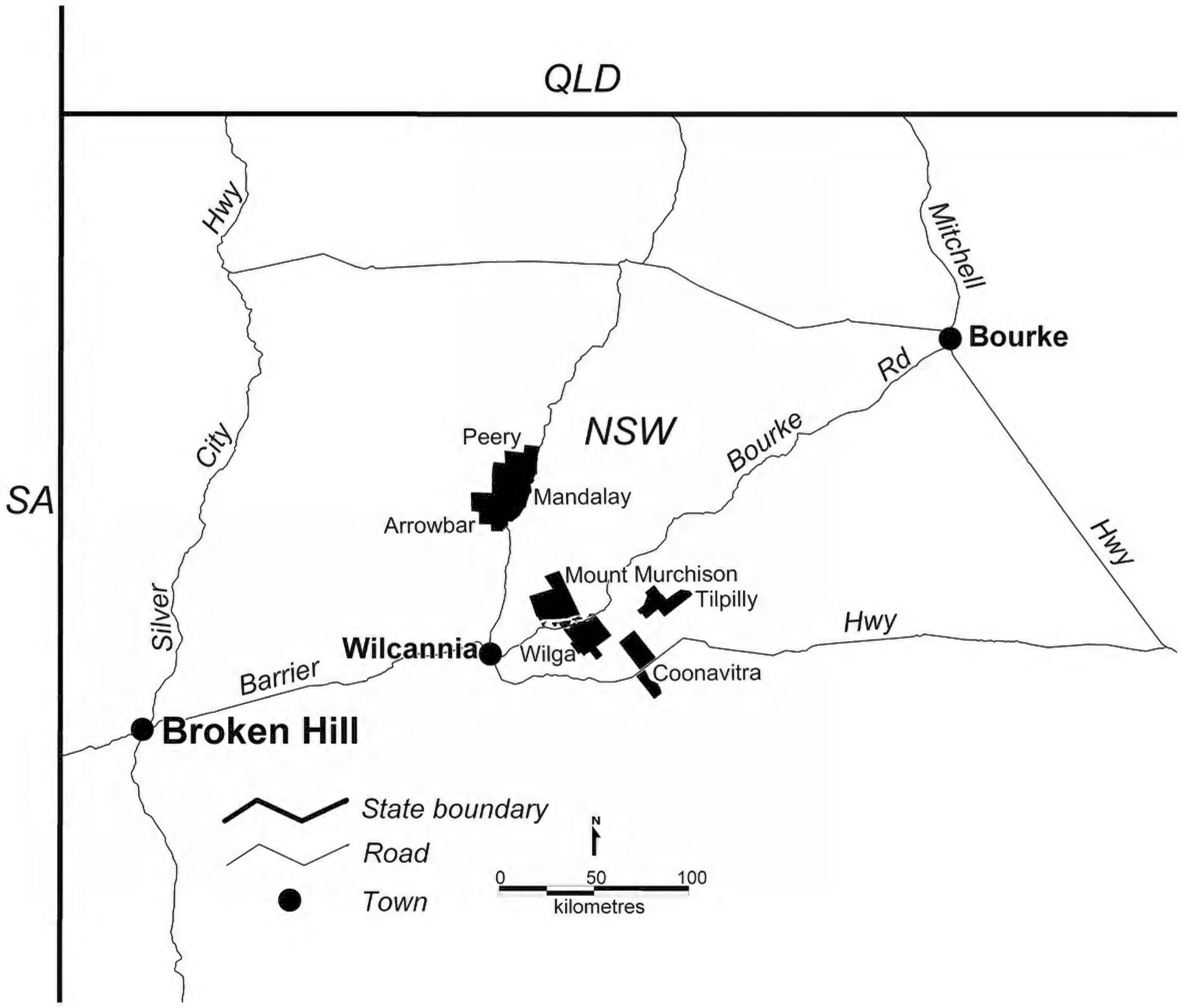

**Fig. 1.** Location of Paroo Darling National Park

*History of the area*

The area is part of the country of the Paakantyi people which extends from Bourke down the Darling River to its junction with the Murray River at Wentworth (Hercus 1993). The large number of middens and stone relics encountered today provides evidence of their strong ties to the river (H. Johnston, New South Wales Parks and Wildlife Service, Buronga, pers. comm.).

The first European to visit the area was Charles Sturt who named the Darling River in honour of Sir Ralf Darling, then Governor of the colony of New South Wales, in 1828. Surveyor General Thomas Mitchell followed in 1835 and after travelling down the eastern side of the Darling from what is now Bourke he crossed the Darling near the site of Wilcannia and climbed a hill which he named Mt Murchison. Sturt later followed the Darling River to Menindee and then travelled west to the Barrier Range and north into Queensland (Stanley 1991). Soon after, others followed the Darling River in search of pasture for sheep. Between 1855 and 1860 Hugh and Bushby Jamieson leased a number of runs near the Paroo-Darling junction which were managed together as Mt Murchison Station (Hope & Linsday 2010). The township of Wilcannia was surveyed in 1865 and soon thrived (Hardy 1969). Previously there was just a woolshed and a few huts at Mount Murchison Station. Soon after, 38 runs were taken up as Momba (848,000 ha.) which incorporated the existing Mount Murchison lease (Pickard 1990). Smith, Elder and Waite held the Momba pastoral lease from early 1870 (Heathcote 1965). In 1889 it was reported that Momba was overrun by kangaroos (Heathcote 1965). About this time a party of shooters found opal in the sandstone hills and by the 1890s White Cliffs township was established (Hardy 1969). With the development of pastoral leases in the 1850s, Aboriginal people were moved from their traditional homes to government missions at Menindee, Ivanhoe and Lake Cargelligo.

The combination of drought and overstocking made the normal recurrence of drought a major disaster. Whereas the land returned rapidly from ‘desert’ to ‘vital glory’ after the 1865-70 drought, this was no longer the case by the end of the century. By 1901 there was a catastrophic decline in productivity in the West Darling area. Sheep numbers went from less than two million prior to 1880 to a peak of nearly eight million by 1894 but had declined to less than three million again by 1901. From 1902, Momba was successively subdivided until around 1950 when the residue was divided into ten leases which included Peery, Mandalay, Arrow Bar and Mt Murchison (Pickard 1990).

Peery Station was acquired in 1999 by the NSW government to protect its significant natural and cultural heritage values. Peery National Park was proclaimed in March 2000 (NPWS 2000), and the additions of the Arrow Bar and Mandalay leases in December 2000 gave protection to the entire Peery Lake basin.

In June 2001, the Mount Murchison lease on the northern side of the Darling River was acquired followed by Coonavitra in June 2000. Finally the purchase of Wilga Station, bordering Mount Murchison on the southern bank of the Darling in April 2002 provided a link between the northern and southern properties and led to the proclamation of Paroo Darling National Park, incorporating what had previously been the Peery National Park in October 2002.

The Mount Murchison Station that became part of the Paroo Darling National Park was part of the original Momba Station. The modern Mount Murchison Station dated from March 1926 when the southern part of Momba was subdivided and offered for sale in nine lots, two of them being individual paddocks situated on the banks of the Darling River. Arthur Crossing, a butcher from Cobar, acquired the property and owned it until 1945 when it was sold to William Cook and Edward Marr. Marr acquired Cook's share in 1954. Ownership of the station was put it in the name of Mount Murchison Pty Ltd in March 1983 and the New South Wales National Parks and Wildlife Service acquired most of the Mount Murchison lease in June 2001. Marr retained a small portion of the lease that includes the Mount Murchison homestead.

Wilga Station was formed from the resumed areas of two earlier stations. The present homestead block was originally part of Cultowa Station, while two paddocks added in the 1940s were originally part of Murtee Station. John Plant took over the lease in 1925. The station was divided by watercourses that fed water from the river into large lakes with many parts of the property subject to flooding when the river was high. Pastoral inspectors reports (1963-2001) indicate the stocking levels over several years included 4-8,000 sheep and up to 600 head of cattle. Following John Plant's death in 1960 the property passed to other family members. From July 1985 a cultivation permit enabled cropping on 6175 ha of floodplain country. Raymond Plant died in 1994. Probate issues took some time to conclude and the property was sold to the New South Wales National Parks and Wildlife Service in February 2002 (NPWS 2002).

### *Climate*

The climate for the area is described as arid with low and unreliable rainfall (Edwards 1979). Temperatures are high in summer and mild in winter with average daily maximum of 35°C in January and 17°C in July and average daily minimum of 21°C in January and 4°C in July. The mean annual rainfall is approximately 250 mm and annual potential evaporation is 2738 mm. There is a slight summer bias to rainfall and annual variation is high (Clewett *et al.* 1994).

### *Land systems*

The Mount Murchison area supports a large expanse of sand plains to the north and alluvial plains adjacent to the Darling

**Table 1. Land systems present across the Mount Murchison and Wilga areas (source Walker 1972; Hazelton 1977)**

| **Relief & system** | **Area** | **Characteristics** |
|---|---|---|
| *Plains* | | |
| Oulila (Ou) | Mount Murchison | Slightly undulating plain with few sandy rises, pans and larger drainage sinks. Relief to 5m. Red textured contrast soils and red earths. |
| Vidale (Vi) | Mount Murchison | Plain with calcareous red earths and solonized brown soils with sandy to loamy surface. Relief to 3m. |
| *Alluvial plains* | | |
| Budda (Bd) | Wilga | Undulating plains with recent and ancient dunes, areas of active floodplain. Relief to 10m. Plains with sandy yellow texture-contrast and alluvial soils. Intrusions of grey cracking clays. |
| Denian (De) | Mount Murchison & Wilga | Slightly undulating plains, dunes and alluvial plains bordering floodplains. Relief to 5m. Plains with yellow texture-contrast and alluvial soils. |
| Dunoak (Do) | Wilga | Open level plains with occasional sandy rises, drainage sinks, pans and ancient dunes. Relief to 3m. Sandy yellow or red texture-contrast soils, occasional solonized brown soils, areas of cracking clays with gilgais in drainage sinks and pans. |
| Mid Darling (My) | Mount Murchison & Wilga | Winding perennial stream. Channel incised to 15m. Grey cracking heavy clay soils with small areas of scaldy grey clays on and adjacent to river banks. |
| Nelyambo (NI) | Mount Murchison & Wilga | Open level floodplain of the Darling River, with grey gilgaid and crab-holey, cracking heavy clays. Small pans and minor drainage channels with scaldy grey clays, fringing brown and red cracking clays. |
| *Playas and basins* | | |
| Cobham (Cb) | Mount Murchison | Salt lakes with bare, flat crusted floors of saturated salty brown clay. Pans with deep self-mulching brown clays and brown clays with strong surface crusts. Swamp basins and channels with deep self-mulching brown and grey cracking clays, some with extremely deep and wide cracks. Pan margins with sandy surfaces over earthy pans. Lunettes with deep, loose sand or loamy sand. |
| Paroo Overflow (Po) | Mount Murchison | Extensive overflows of the Paroo River. Grey cracking clays. Isolated islands of scalded light brown loamy sands. |
| Popelloe (Pp) | Wilga | Scalded plains with small stranded lakes and swamps, adjacent to large lakes. Red texture-contrast soils with shallow sandy surface. Small lakes of grey heavy clay, with overlying sandy deposits around shorelines. |
| Thackenbie (Tb) | Wilga | Small to very large lakes filled by floodwaters from Darling River. Large beds with eastern lunettes and otherwise level shorelines, narrow interconnecting channels. Beds, shorelines and channels of grey cracking heavy clays. Lunettes of sandy calcareous or texture-contrast soils. |

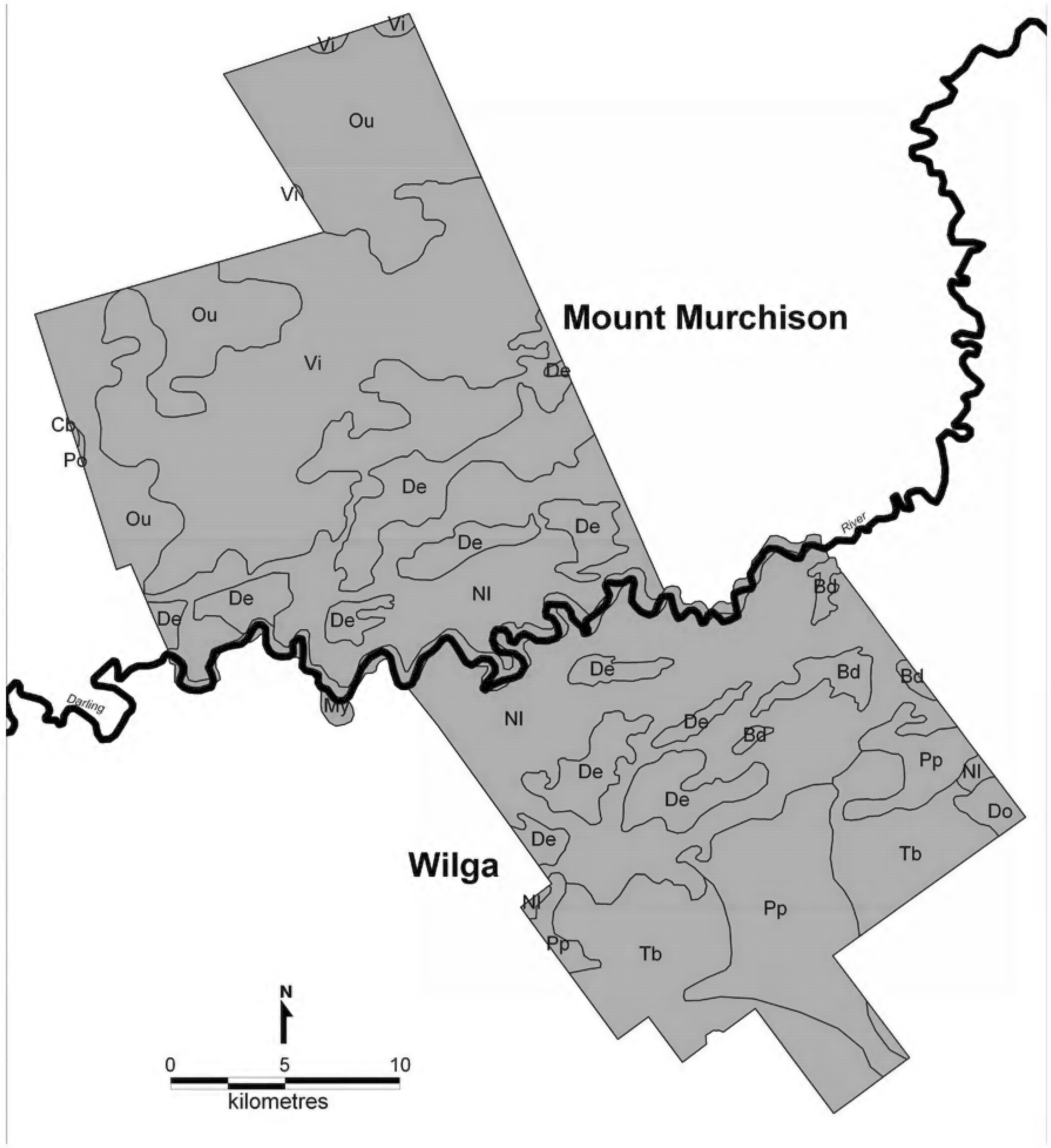

**Fig. 2.** Distribution of land systems within Mount Murchison and Wilga areas, Paroo-Darling National Park (Key to codes used can be found in Table 1)

River. The Wilga area is mostly made up of alluvial plains of the Darling River together with playas and basins in the south. Seven land systems are described for the Mount Murchison area and seven land systems for the Wilga area by Walker (1972) and Hazelton (1977) (Table 1). The distribution of the land systems across the Mount Murchison and Wilga areas is shown in Fig 2.

### *Previous studies*

The most complete study of the vegetation of far western New South Wales is that by Beadle (1945; 1948) who classified the study area as *Casuarina pauper* / *Alectryon oleifolius* subsp. *canescens* association along with claypans and swamps associated with the Darling River. Milthorpe (1991) gave an account of the vegetation of the north-west corner of New South Wales, which included the land that is now known as the Peery Lake area of Paroo Darling National Park. Pickard and Norris (1994) have also given an account of the vegetation of an area of north-west New South Wales. Parts of the area now included in the Park were included in studies undertaken for the Wilderness Society (Lembit 1993; Knight 1994). A detailed survey and vegetation map have been completed for the Peery Lake area (Westbrooke *et al.* 2002; Westbrooke *et al.* 2003), the Tilpilly area (Hunter & Fallavollita 2003) and Coonavitra area (Westbrooke *et al.* 2006; Westbrooke *et al.* 2011) of the park. No systematic survey of the vegetation of the Mount Murchison and Wilga areas of the park had been undertaken prior to this study.

## Methods

### *Study area*

The Mount Murchison area of Paroo Darling National Park is located approximately 40 km north-east of Wilcannia. It incorporates approximately 41,600 ha of the former Mount Murchison Station. The Mount Murchison study area is situated to the north of the Darling River and includes around 47 km of Darling River frontage.

The southern part of the Mount Murchison study area falls within the Darling Riverine Plains bioregion that takes in the riverine corridor and the floodplains of the Darling River. The northern part of the Mount Murchison study area falls within the Mulga Lands bioregion taking in undulating sand plains. The Paroo River flows into the Darling River just west of the study area. Part of the Paroo Overflow extends into the western section of Mount Murchison.

Following significant rainfall and flooding, a number of lakes, swamps and channels on the floodplain adjoining the Darling River carry water. In the south-eastern part of the study area, Jamieson Creek can hold water for prolonged periods after heavy rain. Eight named tanks (McIntyres Plain, Twin, Dead Mans Swamp, Great Eastern, Seawoods Hut, Tallandra, Forest Hut and McQueens Tanks), a few unnamed tanks and three named bores (Eight Mile, Tallandra and Salt Bores) (Fig. 3) were constructed to provide water for stock prior to the park being gazetted.

The Wilga area of Paroo Darling National Park is located approximately 50 km north-east of Wilcannia on the Wilcannia-Bourke Road and incorporates approximately 33,250 ha of the former Wilga Station. The Wilga study

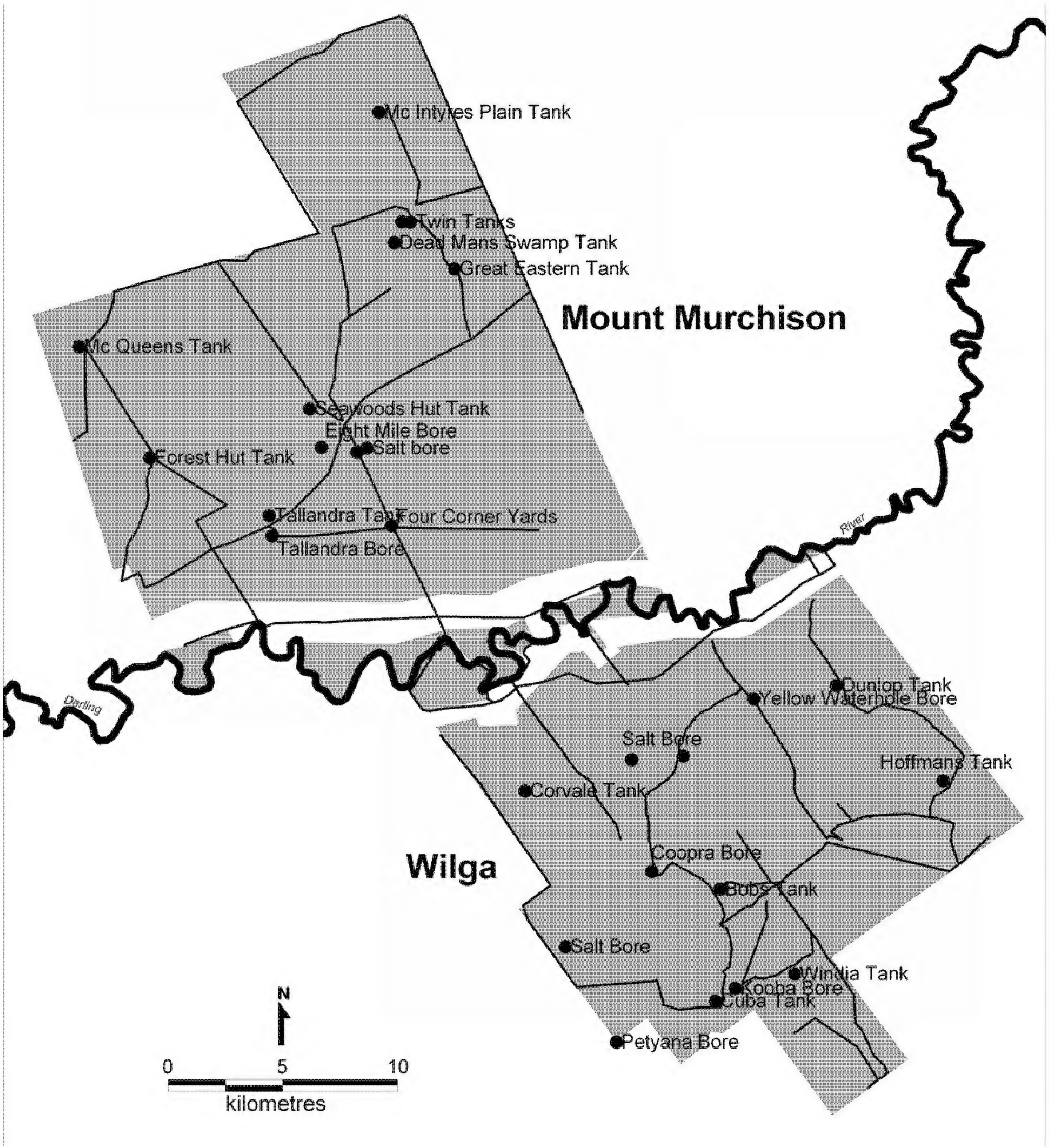

**Fig. 3.** Survey transects for the Mount Murchison and Wilga areas

area is bounded to the north-west by the Darling River and includes around 40 km of Darling River frontage. The Wilga homestead and shearer's quarters are situated on the southern bank of the Darling River just west of Papepapinbilla Creek.

The Wilga study area falls within the Darling Riverine Plains bioregion. There are a number of ephemeral creeks (Talyawalka, Lake, Coopara and Papepapinbilla Creeks), channels and waterholes on the Darling River floodplain. These areas flow or fill for a short time following major rainfall events. The southern part of the study area takes in the northern extents of Poopelloe and Wongalara Lakes. Five named tanks (Dunlop, Bobs, Cuba, Corvale and Windia), a few unnamed tanks and four named bores (Yellow Waterhole, Salt, Coopra and Kooba) (Fig. 3) provided water for stock prior to the park being gazetted.

### *Transect survey*

A preliminary survey to assess and map the vegetation communities present within the Mount Murchison and Wilga areas of Paroo Darling National Park was undertaken during June 2005, following three years of drought. A transect based sampling strategy was employed. Driven transects followed existing vehicle access tracks and fence lines, and additional walked transects were used to access more remote areas. All transects were tracked using a Global Positioning System (GPS) receiver in the Australian Map Grid projection (Zone 54 and 55) and the 1984 World Geodetic System datum. The survey included approximately 335 km of transects (Fig. 3).

Vegetation communities along these transects were recorded and dominant perennial species listed for each community. Details of how information was collected along these transect and used to define vegetation communities to produce a vegetation map at a scale of 1: 50,000 are outlined below.

### *Quadrat survey*

A detailed floristic survey was undertaken during November 2005 following good winter rainfall. A quadrat based sampling strategy was employed to survey the floristic composition of the vegetation communities. All quadrats were 900 m2 (30 m x 30 m) in size. The sampling strategy was based on the preliminary vegetation map prepared following the June survey. Communities were generally sampled in proportion to the area they covered but to enable characterisation of communities, those of limited distribution may have been relatively over-sampled. All quadrat locations were recorded using a Global Positioning System (GPS) receiver in the Australian Map Grid projection (Zone 54 and 55) and the 1984 World Geodetic System datum. All vascular plant species occurring in each quadrat were recorded, identified to species level where possible and their conservation status determined. All flora were given a cover / abundance value, modified from Braun-Blanquet scale as cited in Kershaw and Looney (1985) (Table 2).

**Table 2. Modified Braun-Blanquet scale (Kershaw & Looney 1985)**

| Scale | Definition |
|---|---|
| + | Few individuals, less than 1% cover |
| 1 | Any number of individuals, less than 5% cover |
| 2 | Any number of individuals, 6-25% cover |
| 3 | Any number of individuals, 26-50% cover |
| 4 | Any number of individuals, 51-75% cover |
| 5 | Any number of individuals, 76-100% cover |

The field survey was undertaken during early spring following good winter rains to take advantage of the opportunities for plant identification, particularly of grasses, herbs and forbs. Some later spring-flowering grasses, herbs and forbs may have been dormant at this time and not observed. Similarly, earlier spring-flowering plants may have completed their growth cycles and may not have been observed. Where dead material (e.g. leaves, stems, seeds) was available such species were recorded to family, genus or species level where possible.

An estimate of the typical height and a visual estimate of the projected foliage cover of both native and introduced species in the tree layer, tall shrub layer (approximately > 1 m high), small shrub layer (approximately < 1 m high) and ground layer were recorded for each quadrat. Visual estimates of the total percentage cover of bare ground, cryptogams, litter, logs and rocks were recorded for each quadrat. All quadrats were photographed to provide a visual record. Forty seven quadrats were sampled for the Mount Murchison area and 55 quadrats for the Wilga area (Fig. 4).

During the November quadrat survey, the 1: 50,000 vegetation map produced following the June field survey was verified by ground checking the mapped boundaries of the vegetation communities via driven transects.

### *Data analysis*

Information from the transects was used in conjunction with the study of colour aerial photographs (The Department of Lands) and Landsat Thematic Mapper satellite imagery (Scene 95-83) to produce a vegetation map at 1: 50,000 scale. Vegetation mapping was undertaken using a combination of ArcGIS 9.0 and MapInfo Professional Version 7.5 Geographic Information Systems. The mapped vegetation communities were defined by floristic and structural characteristics (Specht 1970) coupled with expert judgment. The communities proposed were related to those outlined in Benson (2006) to determine the equivalent vegetation community name and their conservation status. Most communities with patch sizes of a hectare or greater were mapped as polygons and those of restricted occurrence were located as points on the map.

Data from quadrats were entered into a Microsoft® Access 2002 database. A species list was compiled for the study area incorporating all vascular plant species recorded from quadrats and additional species recorded opportunistically. The flora list also identifies which vegetation community each of the species was recorded in. For each vegetation community, mean species richness, total species richness and mean numbers of introduced species per quadrat were calculated.

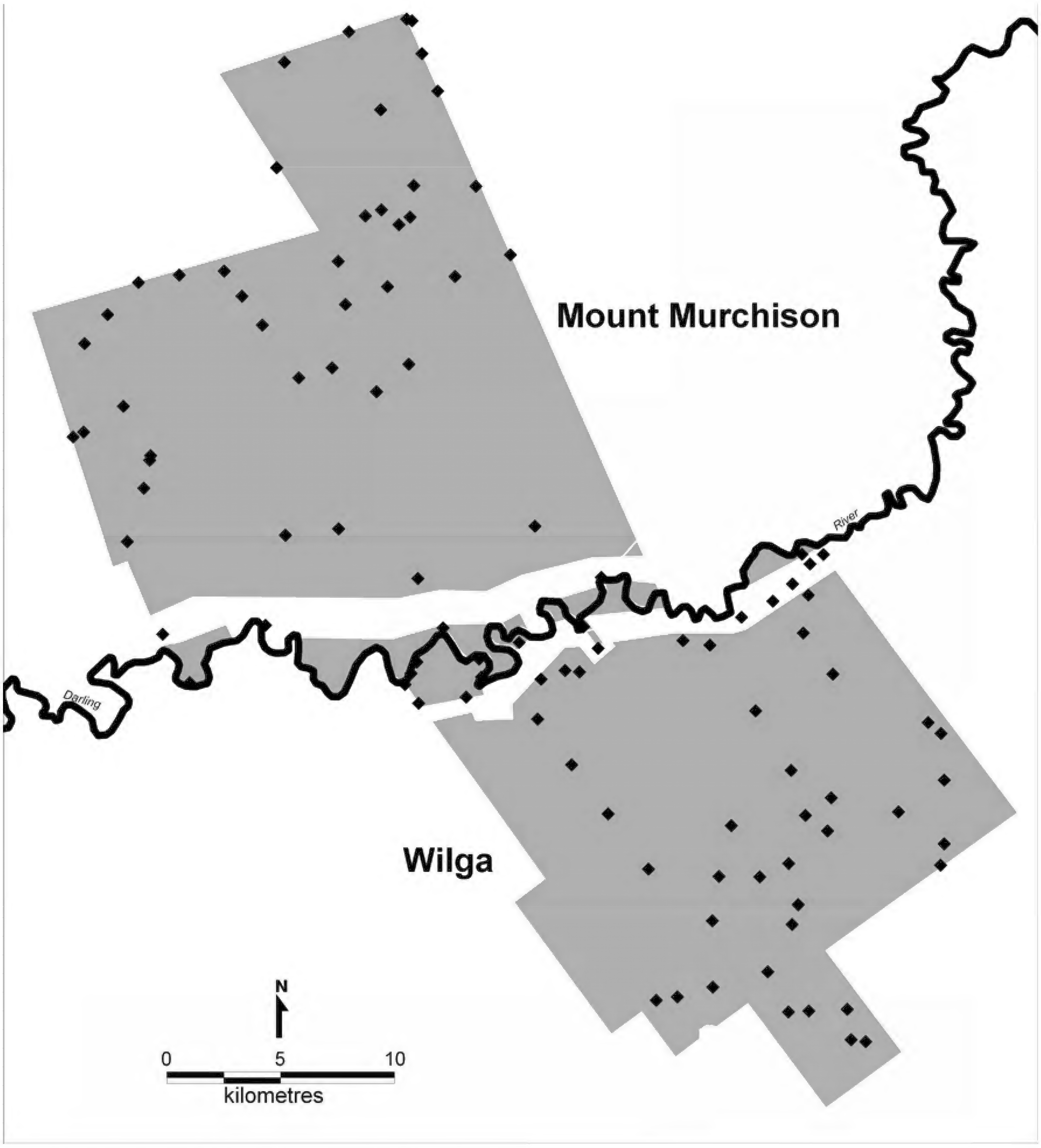

**Fig. 4.** Quadrat locations for the Mount Murchison and Wilga areas

## Results

### *Vegetation*

The Mount Murchison area consists of a strip of *Eucalyptus camaldulensis* open woodland along the banks of the Darling River, *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland and *Muehlenbeckia florulenta* open shrubland on the Darling River floodplains, with *Maireana pyramidata* low open shrubland on the adjoining sandplains. Off the floodplain, *Flindersia maculosa* low open woodland and *Casuarina pauper / Alectryon oleifolius* low open woodland occur on level sandplains.

The vegetation of the Wilga area consists predominantly of floodplains of *Muehlenbeckia florulenta* open shrubland and *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland. A strip of *Eucalyptus camaldulensis* open woodland occurs along the banks of the Darling River. The sandplains to the south of the river are variously dominated by *Acacia victoriae* open shrubland and a mixed open shrubland complex.

Seventeen communities were recognised for the Mount Murchison and Wilga areas, 15 for Mount Murchison area and 13 for the Wilga area. All vegetation communities are identified in Table 3 and are grouped according to structural attributes. While several of these are of limited distribution they add significantly to the conservation values of the Park. The floristic composition of vegetation communities are outlined later in this section. A total list of flora species recorded for each vegetation community is provided in Appendix 1. Appendix 2 shows the distribution of each vegetation community.

**Table 3. Vegetation communities of the Mount Murchison and Wilga areas with their relationship to soil and landform**

Note: The total mapped area is approximately 45,398 ha for the Mount Murchison area and 35,918 ha for the Wilga area. This includes the park and also areas outside the reserve extending to the Darling River. Point locations of communities (i.e. Anthropogenic herbland) have been treated as occupying approximately 1 ha. Equivalent Benson (2006) vegetation community I.D. numbers are shown in brackets.

| **Vegetation community** | **Area (ha) approx** | | **Soil and landform** |
|---|---|---|---|
| | **Mt Murchison** | **Wilga** | |
| **Woodlands** | | | |
| *Atalaya hemiglauca* low open woodland (137) | 456 | 1 | Calcareous plains of the Oulila landsystem of Mount Murchison and the Popelloe landsystem of Wilga. |
| *Casuarina pauper / Alectryon oleifolius* low open woodland (58) | 1,284 | - | Calcareous sandplains of the Oulila, Vidale and Denian landsystems. |
| *Eucalyptus camaldulensis* open woodland (36) | 242 | 249 | Fringing the Darling River of the Mid-Darling landsystem. |
| *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland (38) | 5,034 | 8,113 | Darling River floodplain of the Nelyambo landsystem of both Mount Murchison and Wilga, the Denian landsystem of Mount Murchison and the Thackenbie landsystem of Wilga. Fringing lakebeds of the Vidale and Oulila landsystems for Mount Murchison and the Denian and Budda landsystems of Wilga. |
| *Flindersia maculosa* low open woodland (144) | 9,996 | 1 | Aeolian sands and calcareous plains of the Vidale landsystem of Mount Murchison and the Popelloe landsystem of Wilga. |
| **Tall shrublands** | | | |
| *Acacia aneura* tall open shrubland (plains) (119) | 383 | - | Footslopes of hills of the Oulila landsystem of Mount Murchison. |
| *Acacia ligulata* tall open shrubland (124) | - | 1,098 | Undulating plains and dunes of the Denian landsystem of Wilga |
| *Hakea leucoptera* tall open shrubland (199) | 13 | 11 | Plains of the Oulila and Nelyambo landsystems of Mount Murchison and the Poppelloe landsystem of Wilga. |
| **Low shrublands** | | | |
| *Acacia victoriae* open shrubland (139) | 89 | 2,569 | Undulating plains and dunes of the Denian landsystem for both Mount Murchison and Wilga, the Nelyambo landsystem of Mount Murchison and the Budda, Dunoak and Popelloe landsystems of Wilga. |
| *Atriplex nummularia* open shrubland (158) | 518 | - | Sub-terminal basins and floodplains of the Paroo River, of the Paroo Overflow and Oulila landsystems of Mount Murchison. |
| *Eremophila / Dodonaea / Senna* open shrubland (143) | - | 4,604 | Sandy rises within alluvial plains of the Popelloe landsystem of Wilga. |
| *Maireana pyramidata* low open shrubland (153) | 16,785 | - | Quaternary sandplains of the Oulila, Vidale and Denian landsystems of Mount Murchison. |
| *Muehlenbeckia florulenta* open shrubland (25) | 8,718 | 15,283 | Lakebeds of Darling River floodplain of the Nelyambo landsystem of both Mount Murchison and Wilga and the Thackenbie landsystem of Wilga. |
| **Grasslands** | | | |
| *Eragrostis australasica* grassland (24) | 367 | 116 | Lakes and depressions within quaternary plains of the Oulilla landsystem of Mount Murchison and the Popelloe landsystem of Wilga. |
| **Herblands** | | | |
| Anthropogenic herbland | 14 | 14 | Areas subject to significant disturbance, including earth tanks and yards. |
| Cropped lakebed | 735 | 910 | Darling River floodplain lakes. |
| Lakebed herbland (166) | 529 | 2,768 | Darling River overflow lakes and floodplains of the Nelyambo landsystem of both Mount Murchison and Wilga, the Oulila and Vidale landsystems of Mount Murchison and the Thackenbie landsystem of Wilga. |

### *Woodlands*

#### *Atalaya hemiglauca* low open woodland

Small areas of *Atalaya hemiglauca* low open woodland (Fig. 5) occur on sandplains in the north of the Mount Murchison block and in the south of the Wilga block. Associated understorey shrubs include *Maireana pyramidata*, *Chenopodium curvispicatum* and *Atriplex* species. Ground layer species include *Austrostipa scabra*, *Brachyscome lineariloba*, *Daucus glochidiatus*, *Plantago turrifera* and *Rhodanthe corymbiflora*.

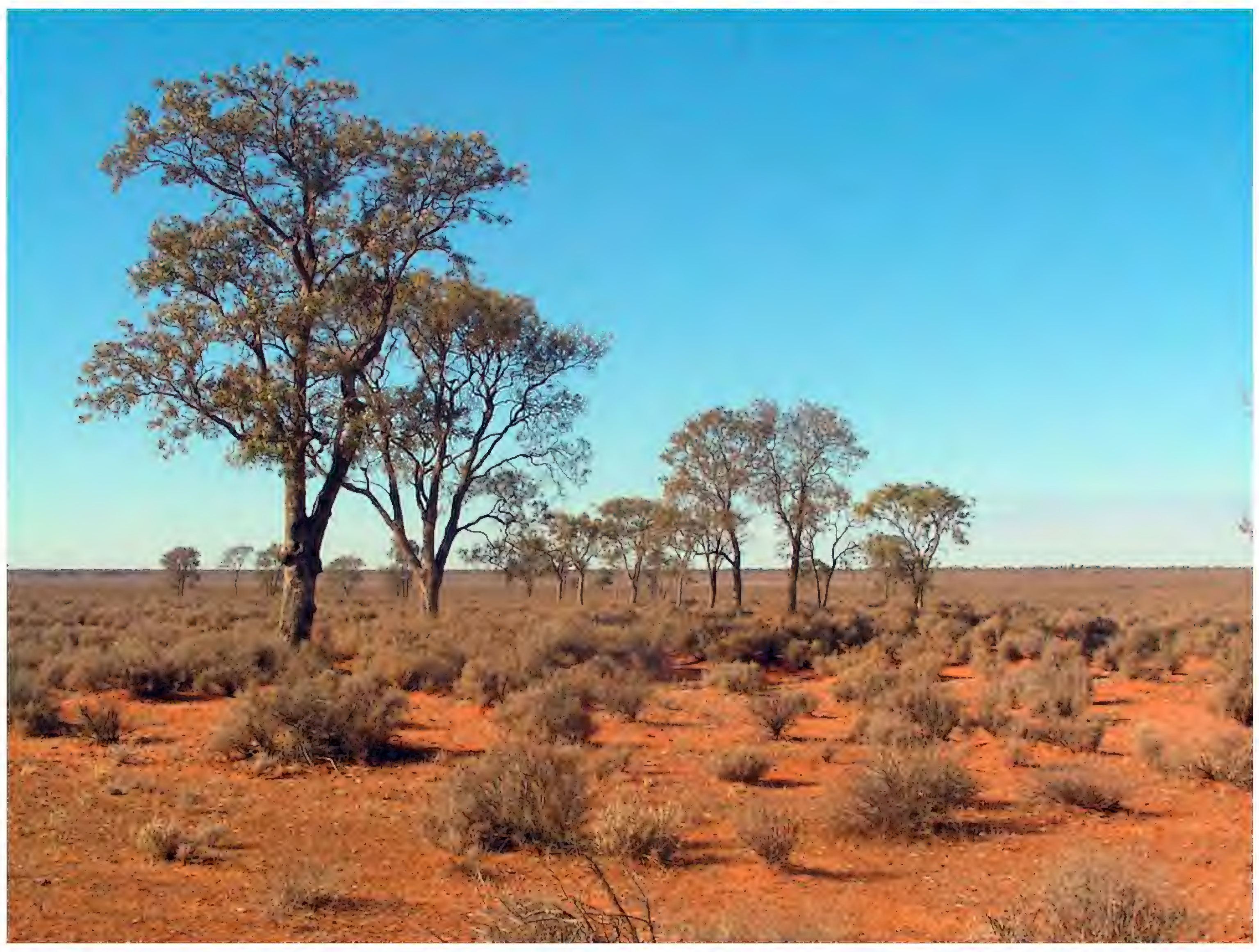

**Fig. 5.** *Atalaya hemiglauca* low open woodland

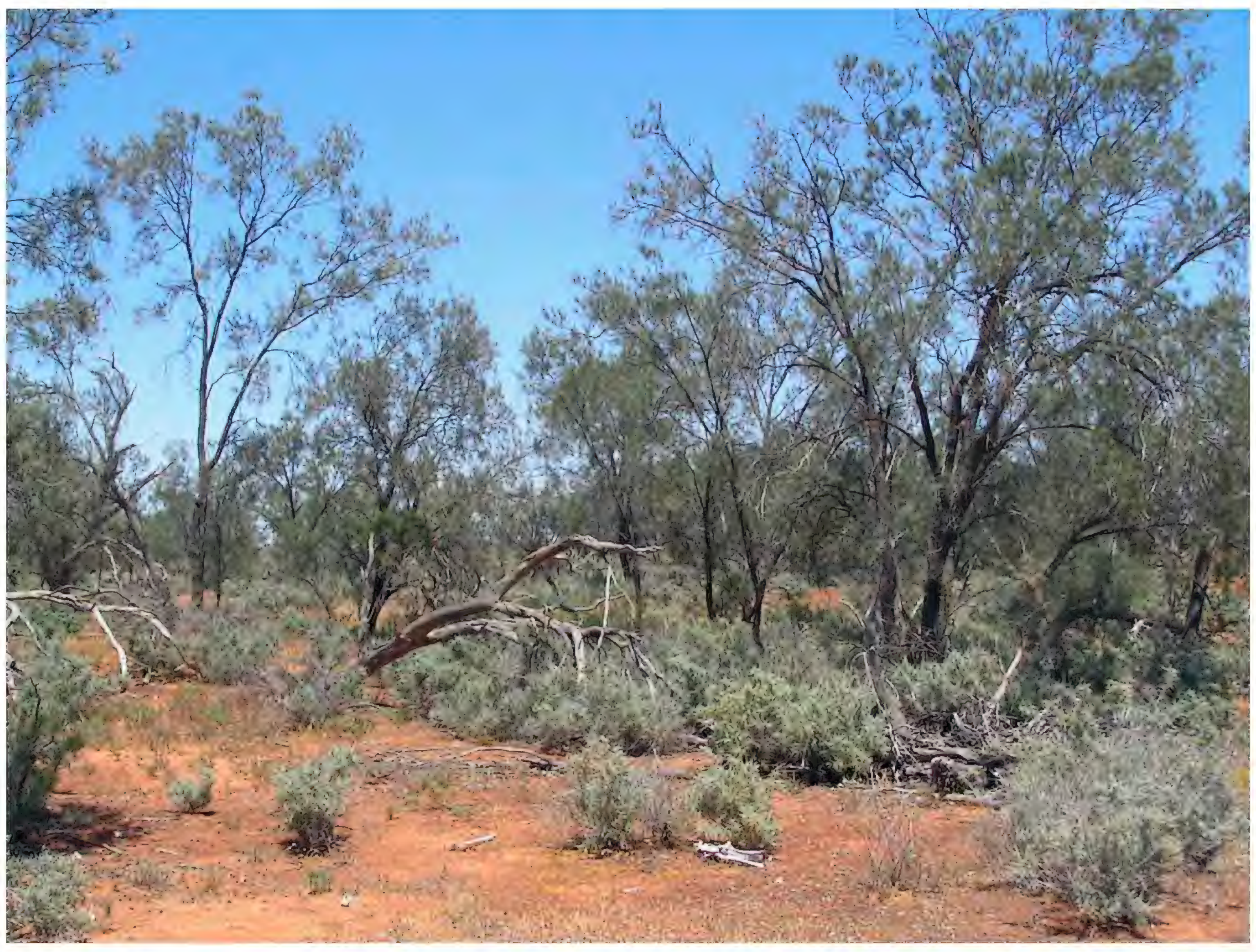

**Fig. 6.** *Casuarina pauper / Alectryon oleifolius* subsp. *canescens* low open woodland

#### *Casuarina pauper / Alectryon oleifolius* subsp. *canescens* low open woodland

*Casuarina pauper / Alectryon oleifolius* subsp. *canescens* low open woodland (Fig. 6) growing to 10-12 metres tall occurs on undulating sandplains. Most commonly associated understorey shrubs are *Maireana pyramidata, Atriplex holocarpa, Chenopodium curvispicatum, Enchylaena tomentosa* and *Sclerolaena intricata*. Commonly associated ground layer species include *Rhodanthe corymbiflora, Gnephosis foliata, Lepidium oxytrichum, Austrostipa scabra* and *Plantago drummondii*.

#### *Eucalyptus camaldulensis* open woodland

*Eucalyptus camaldulensis* open woodland (Fig. 7) (10 metres tall) occurs in a generally narrow band along the Darling River frontage and some major associated creeks and channels. Common associated trees include *Eucalyptus coolabah* subsp. *coolabah* and *Acacia stenophylla*. Understorey shrub species frequently associated include *Enchylaena tomentosa, Chenopodium nitrariaceum* and *Atriplex leptocarpa*. Ground layer species include *Einadia nutans, Senecio runcinifolius, Chamaesycce drummondii, Swainsona greyana* and *Rumex* species. *Muehlenbeckia florulenta* is also frequently associated.

#### *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland

Large areas of *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland (Fig. 8) (10 m tall) occur on heavy soils

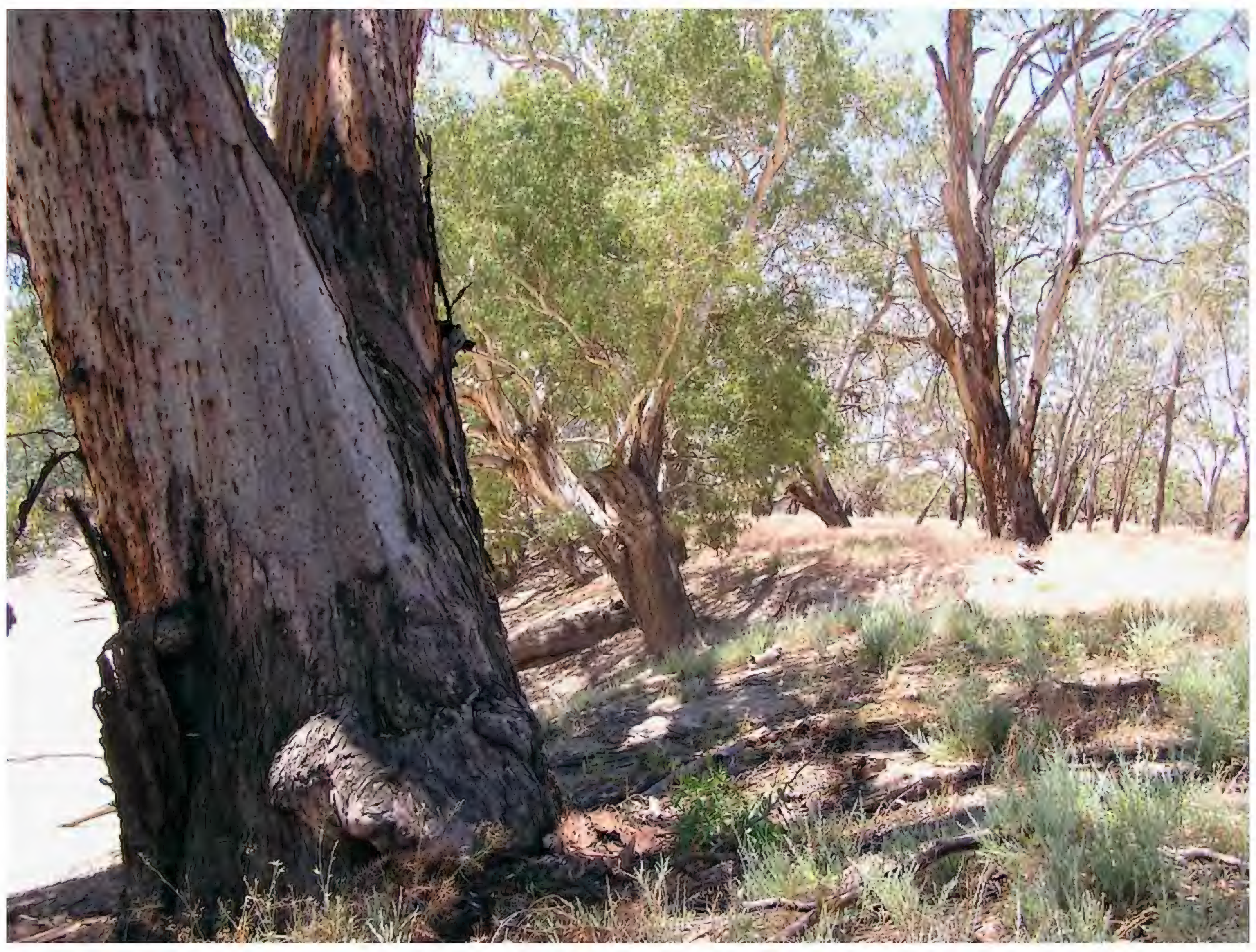

**Fig. 7.** *Eucalyptus camaldulensis* open woodland

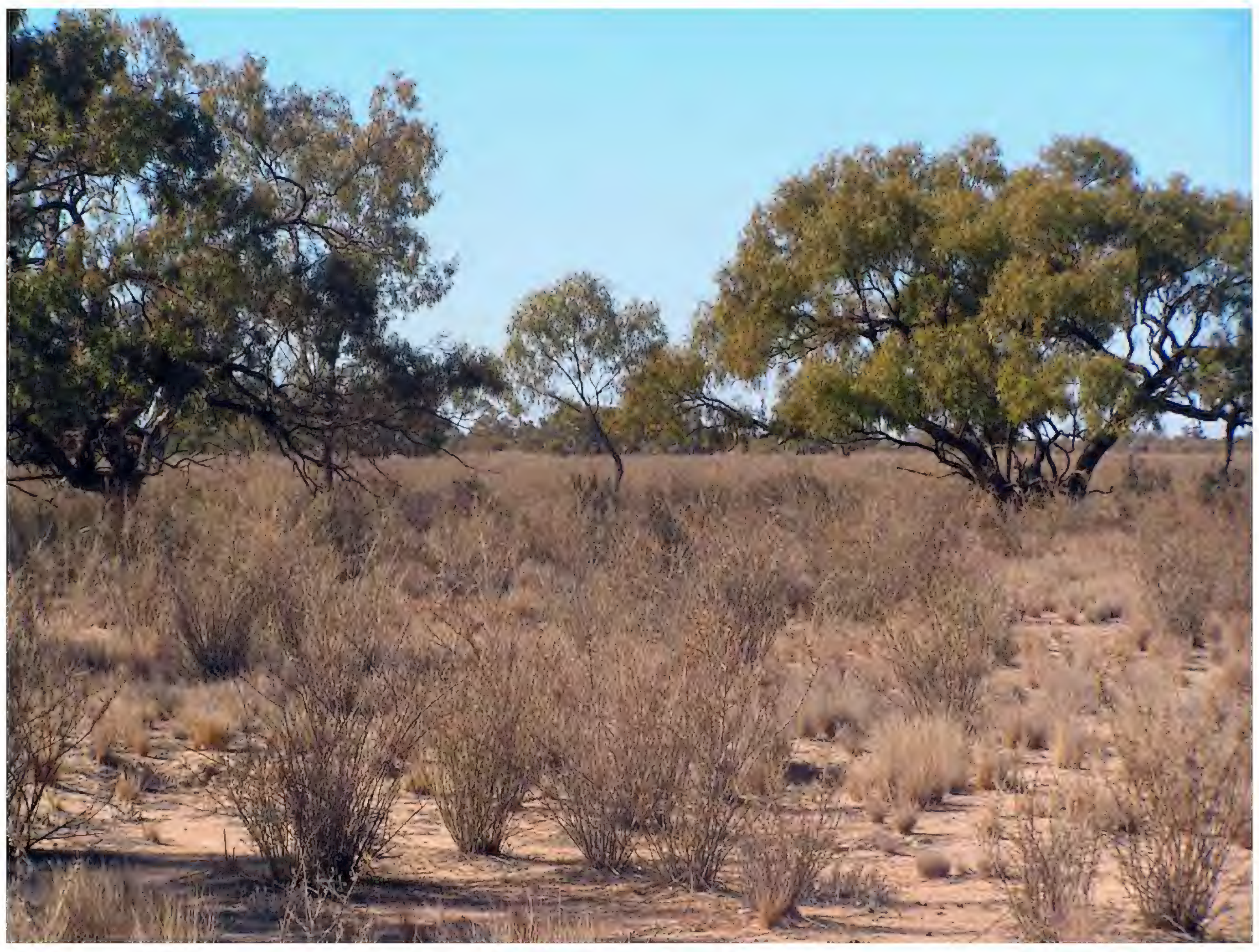

**Fig. 8.** *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland

associated with the Darling River flood plain. *Muehlenbeckia florulenta* is often present and other frequently associated understorey shrubs include *Chenopodium nitrariaceum, Enchylaena tomentosa, Sclerolaena intricata* and *Sclerolaena muricata*. Associated ground layer species include *Einadia nutans, Rhodanthe corymbiflora, Plantago turrifera, Plantago drummondii, Pycnosorus pleiocephala* and *Teucrium racemosum*.

### *Flindersia maculosa* low open woodland

Low open woodland dominated by *Flindersia maculosa* (Fig. 9) occurs on low hills and sandplains. *Alectryon oleifolius* subsp. *canescens* is frequently associated. Associated shrubs include *Maireana pyramidata, Dissocarpus paradoxus, Enchylaena tomentosa, Atriplex holocarpa, Sclerolaena intricata, Sclerolaena obliquicuspis, Sclerolaena lanicuspis, Salsola kali* var. *kali* and *Chenopodium curvispicatum*. Ground layer species include *Austrostipa scabra, Gnephosis foliata, Tetragonia eremaea, Stenopetalum lineare, Rhodanthe corymbiflora* and *Vittadinia cuneata*.

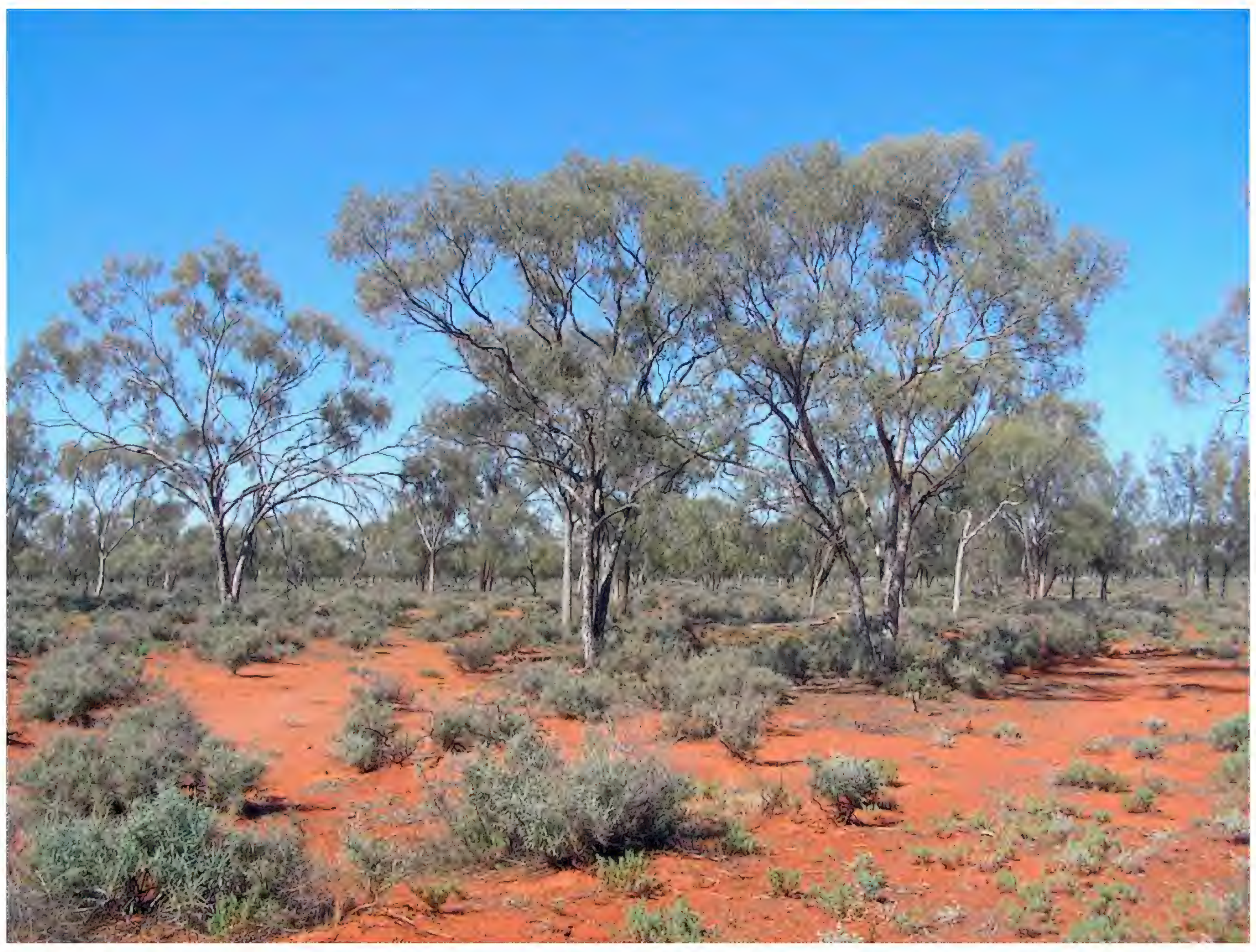

**Fig. 9.** *Flindersia maculosa* low open woodland

## *Tall shrublands*

### *Acacia aneura* tall open shrubland (plains)

Tall open shrubland dominated by *Acacia aneura* (Fig. 10) frequently occurs on undulating sandplains and low hills. Associated shrubs include *Chenopodium curvispicatum, Dissocarpus paradoxa, Dodonaea viscosa* subsp. *angustifolia*, *Enchylaena tomentosa* and *Eremophila sturtii*. Ground layer species include *Abutilon leucopetalum, Austrostipa nitida, Brachyscome lineariloba, Bulbine alata, Einadia nutans, Eragrostis eriopoda, Erodium crinitum, Gnephosis foliata, Harmsiodoxa brevipes* var. *brevipes, Ixiolaena tomentosa, Lepidium muelleri-ferdinandii, Lepidium pseudohyssopifolium, Plantago cunninghamii, Pseudognaphalium luteoalbum, Pycnosorus globosus, Rhodanthe corymbiflora, Sida intricata* and *Solanum esuriale*.

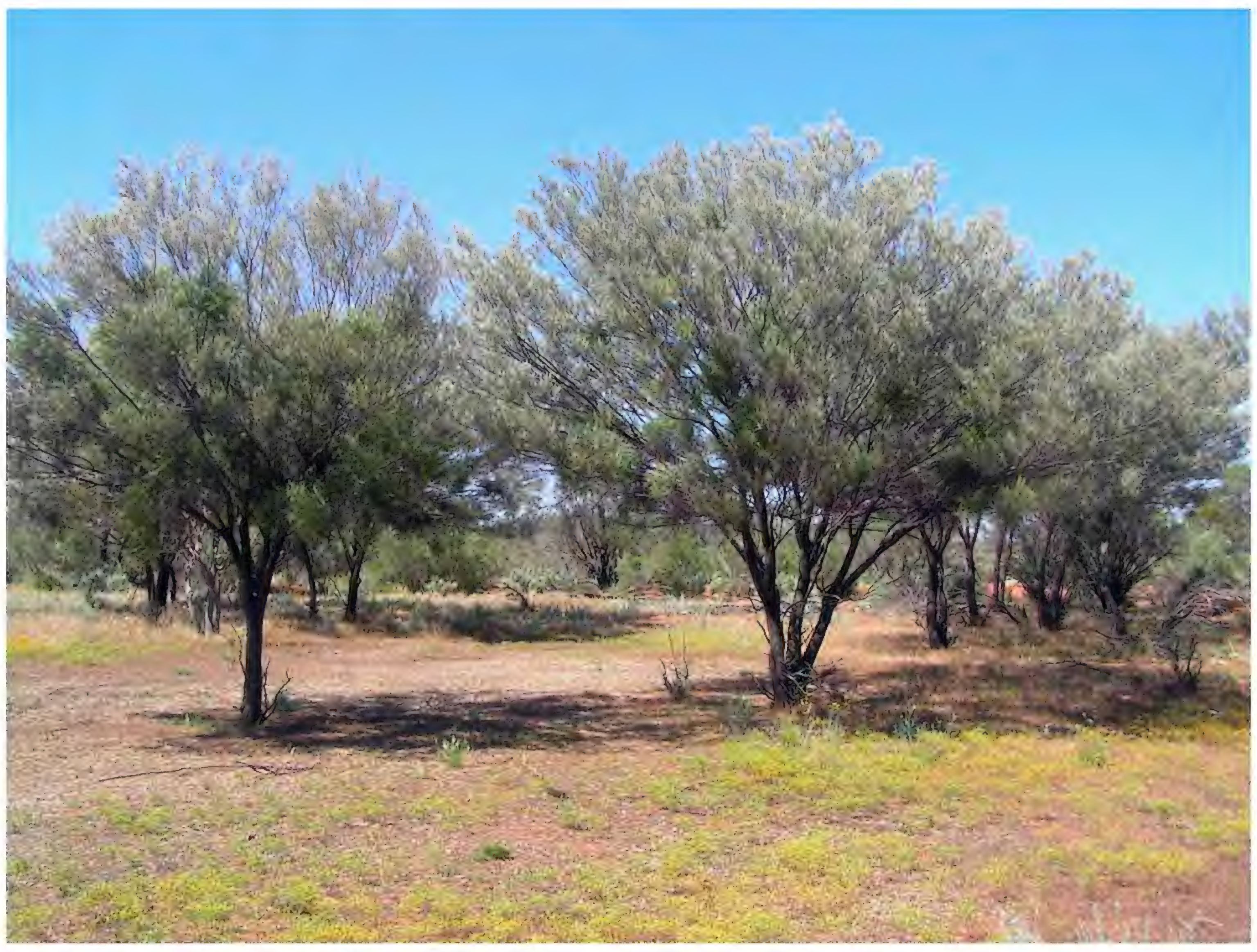

**Fig. 10.** *Acacia aneura* tall open shrubland (plains)

### *Acacia ligulata* tall open shrubland

Tall open shrubland dominated by *Acacia ligulata* (Fig. 11) occurs on deeper sand ridges rising above the plains. Associated shrubs include *Enchylaena tomentosa* and *Salsola kali* var. *kali*. Ground layer species include *Sauropus trachyspermus, Myriocephalus stuartii, Crassula colorata* and *Senecio runcinifolius*.

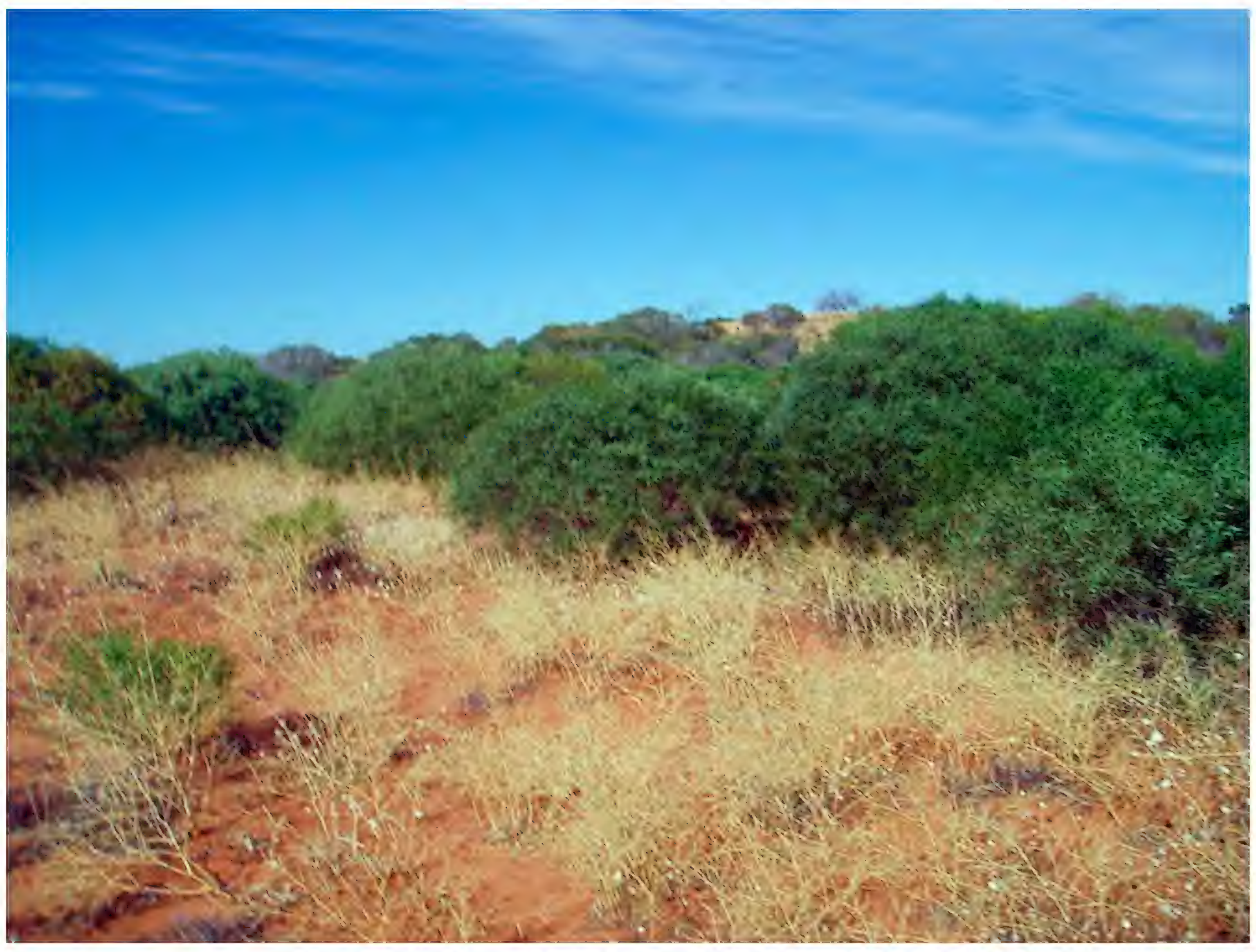

**Fig. 11.** *Acacia ligulata* tall open shrubland

### *Hakea leucoptera* tall open shrubland

Small patches of tall open-shrubland dominated by *Hakea leucoptera* (Fig. 12) occur on sandplains in the south of the Wilga block. Associated shrub species include *Salsola kali* var. *kali*, *Sclerolaena bicornis, Sclerolaena intricata, Dodonaea viscosa* subsp. *angustifolia, Atriplex stipitata* and *Acacia limbata*. Ground layer species include *Austrostipa scabra, Rhodanthe corymbiflora, Osteocarpum acropterum, Teucrium racemosum, Plantago drummondii, Sida intricata, Stenopetalum lineare, Pycnosorus pleiocephala* and *Brachyscome lineariloba*.

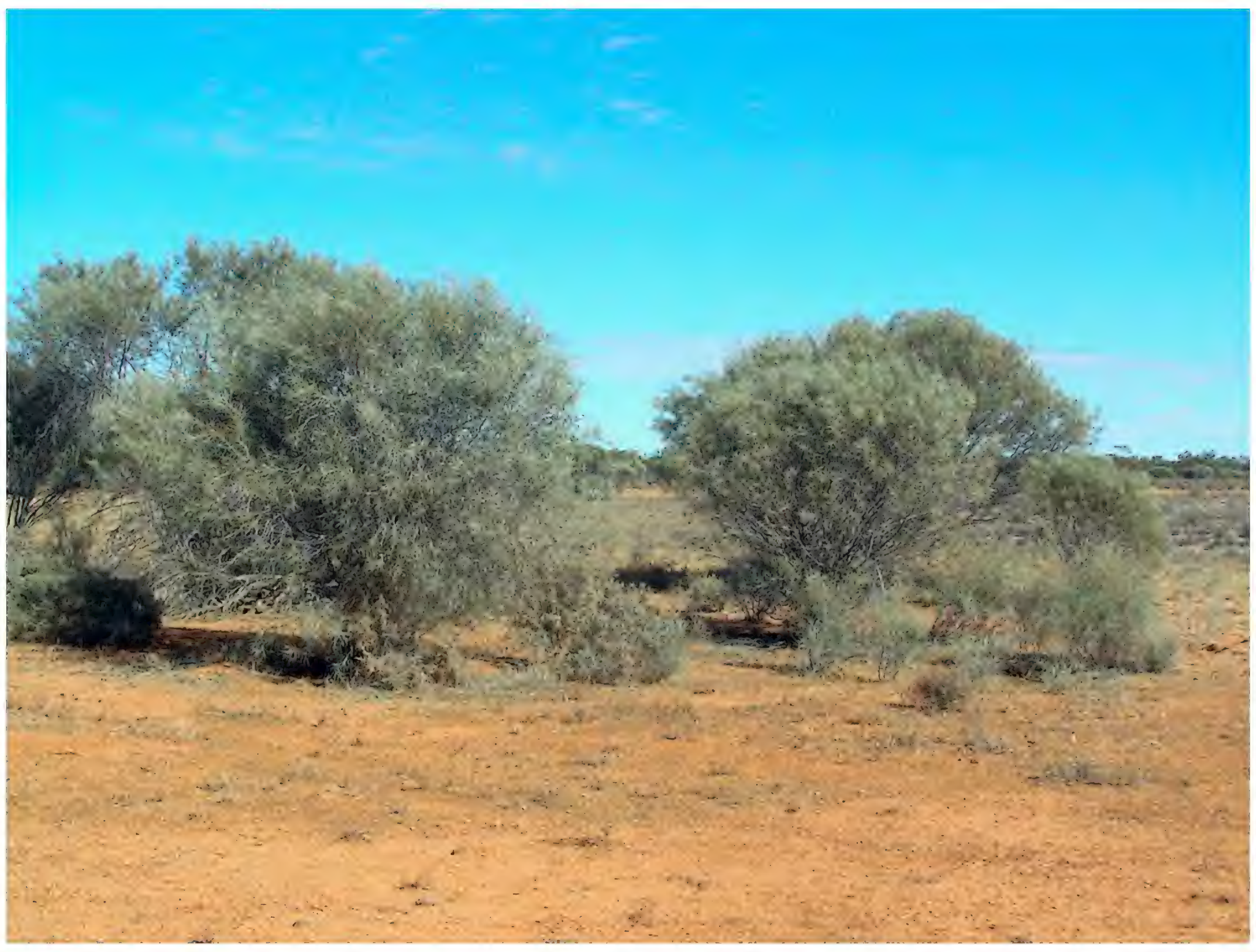

**Fig. 12.** *Hakea leucoptera* tall open shrubland

### *Low shrublands*

### *Acacia victoriae* open shrubland

*Acacia victoriae* open shrubland (Fig. 13) occurs on sandy rises of the allluvial plains on either side of the Darling River. Associated shrub species include *Enchylaena tomentosa, Sclerolaena bicornis* var. *bicornis, Sclerolaena diacantha* and *Maireana pyramidata*. Ground layer species include *Daucus glochidiatus, Myriocephalus stuartii, Rhodanthe corymbiflora, Einadia nutans, Brachyscome lineariloba, Plantago drummondii, Plantago turrifera, Austrostipa scabra, Sida intricata* and *Pycnosorus pleiocephala*.

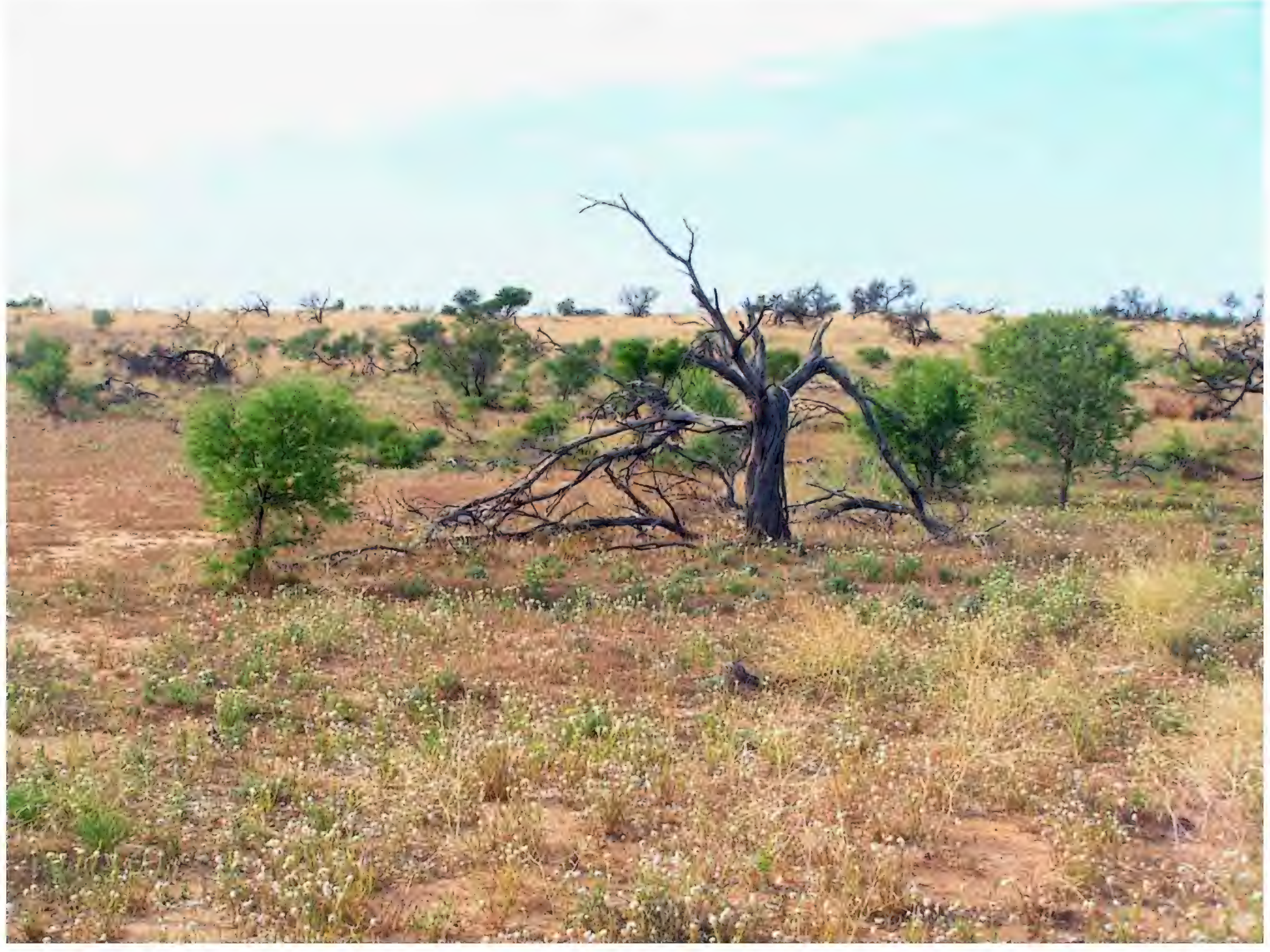

**Fig. 13.** *Acacia victoriae* open shrubland

### *Atriplex nummularia* open shrubland

An open shrub community dominated by *Atriplex nummularia* (Fig. 14) occurs in the east of the Mount Murchison block on the floodplain of the Paroo River. Associated shrub species include *Chenopodium nitrariaceum, Dissocarpus paradoxa, Maireana pyramidata, Sclerolaena obliquicuspis* and *Sclerolaena patenticuspis*. Ground layer species include *Rhodanthe corymbiflora, Agrostis avenacea* var. *avenacea, Atriplex holocarpa, Austrostipa scabra, Centipeda minima, Chamaesyce drummondii, Daucus glochidiatus, Eragrostis australasica, Eragrostis eriopoda, Goodenia pinnatifida, Harmsiodoxa brevipes* var. *brevipes, Ixiolaena leptolepis, Lepidium pseudohyssopifolium, Marsilea drummondii, Muehlenbeckia florulenta, Osteocarpum acropterum, Plantago cunninghamii, Plantago turrifera, Pycnosorus pleiocephala, Sclerochlamys brachyptera, Stenopetalum lineare* and *Teucrium racemosum*.

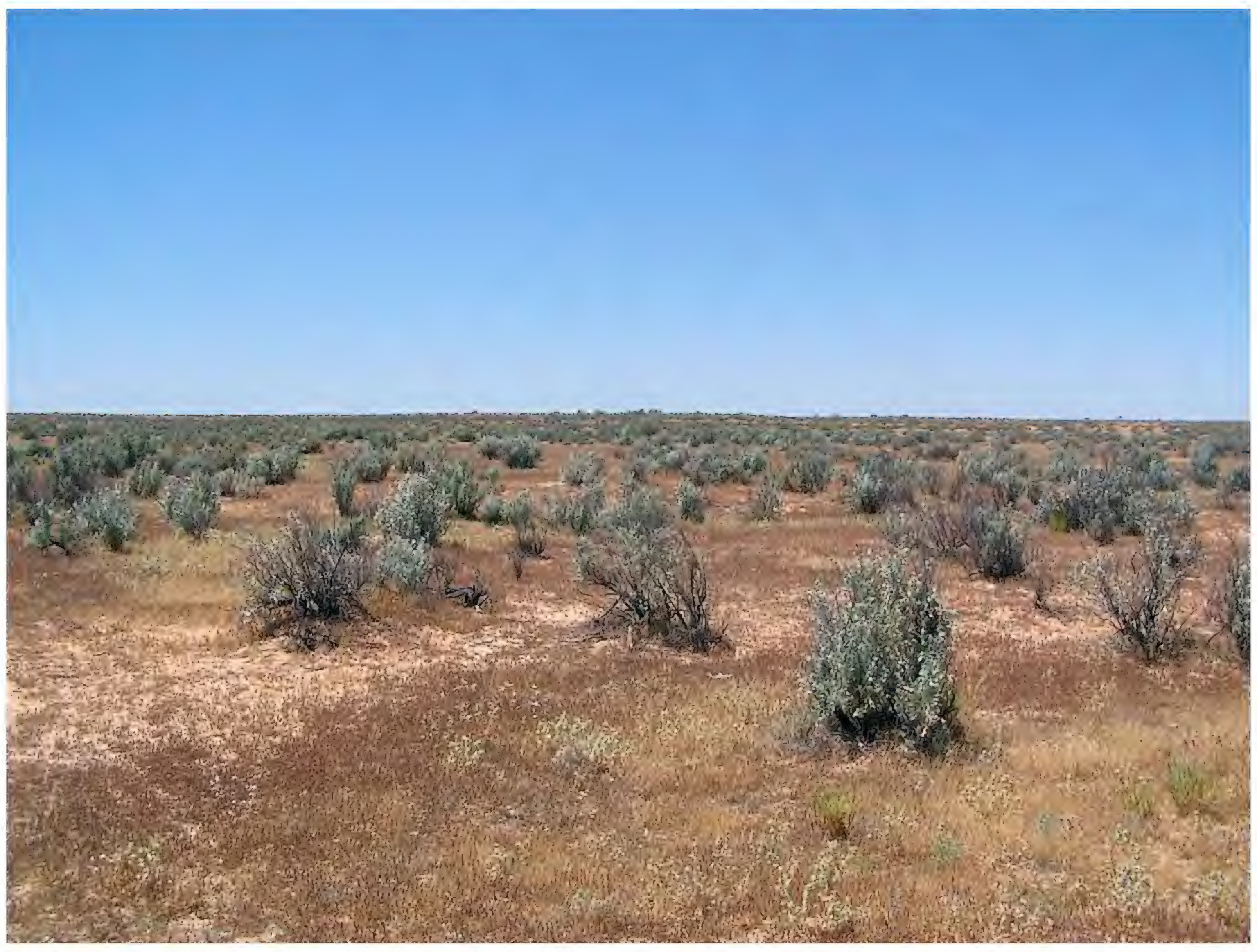

**Fig. 14.** *Atriplex nummularia* open shrubland

### *Eremophila / Dodonaea / Senna* open shrubland

This community is commonly associated with *Casuarina pauper / Alectryon oleifolius* low open woodland. On sandy rises are areas of mixed species shrubland in which *Dodonaea viscosa* subsp. *Angustifolia*, *Eremophila sturtii* and *Senna artemisioides* are prominent (Fig. 15). Other associated shrubs include *Maireana pyramidata, Atriplex stipitata, Sclerolaena diacantha, Sclerolaena intricata, Sclerolaena*

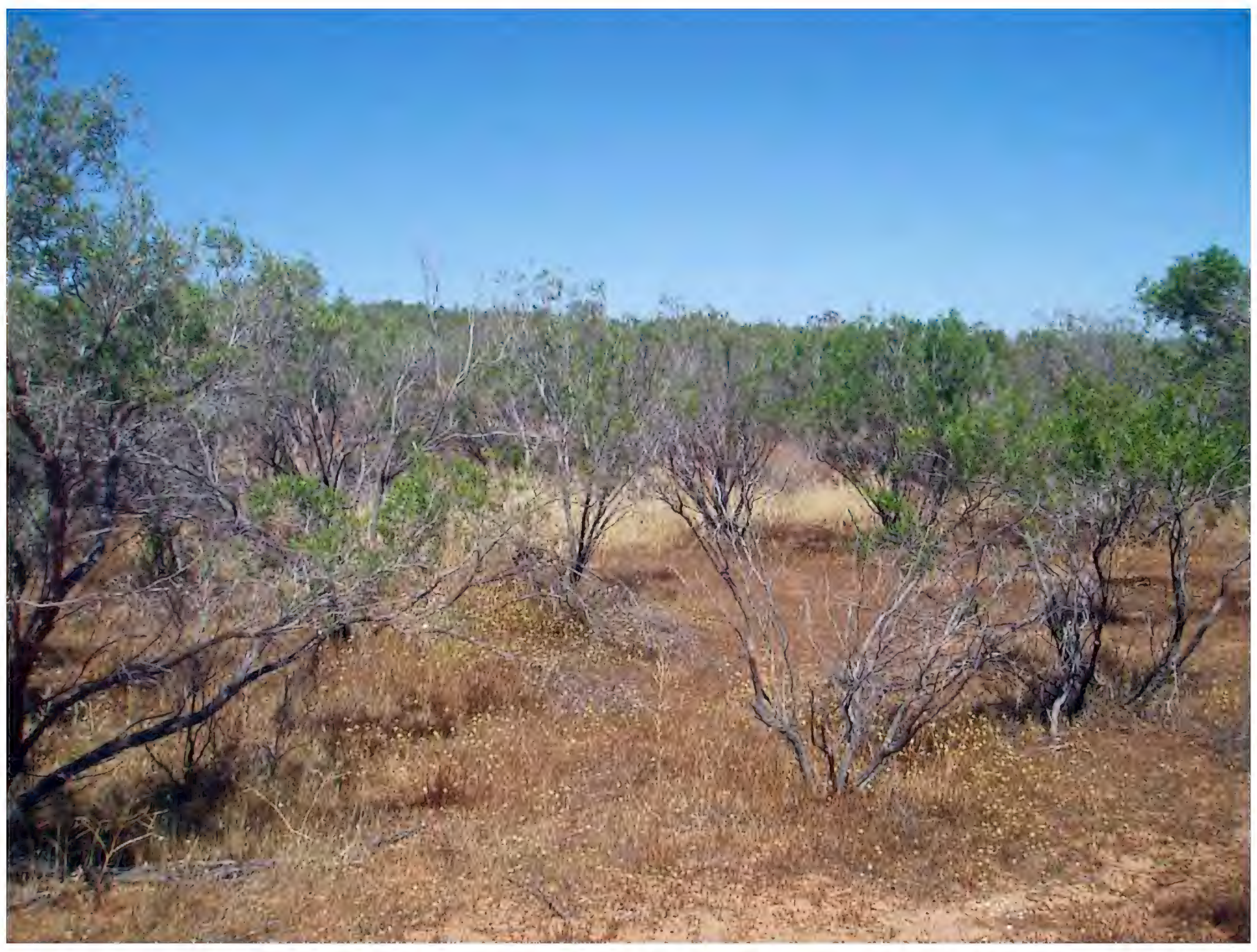

**Fig. 15.** *Eremophila / Dodonaea / Senna* open shrubland

*bicornis* var. *bicornis*, *Enchylaena tomentosa* and *Acacia victoriae*. Common ground layer associates include *Austrostipa scabra, Einadia nutans, Plantago drummondii, Myriocephalus stuartii, Pycnosorus pleiocephala, Brachyscome lineariloba, Goodenia pinnatifida, Teucrium racemosum, Swainsona phacoides, Daucus glochidiatus* and *Rhodanthe corymbiflora*.

### *Maireana pyramidata* low open shrubland

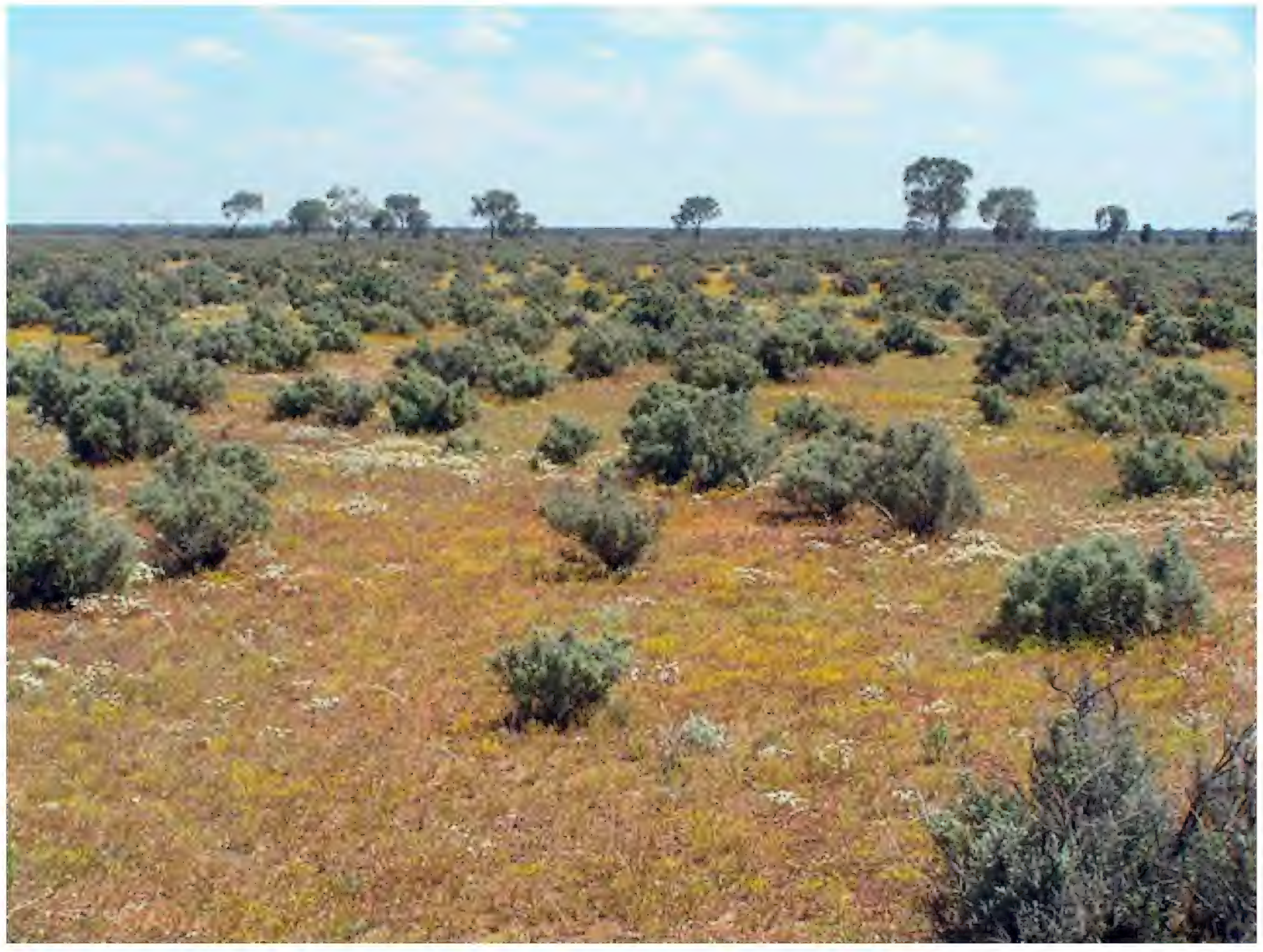

**Fig. 16.** *Maireana pyramidata* low open shrubland

A low open shrubland dominated by *Maireana pyramidata* (Fig. 16) occurs on sandplains and lower slopes of rises. Commonly associated shrubs include *Atriplex holocarpa, Dissocarpus paradoxus, Sclerolaena obliquicuspis* and *Chenopodium curvispicatum*. Ground layer species include *Rhodanthe corymbiflora, Austrostipa scabra, Pycnosorus pleiocephala, Plantago turrifera, Vittadinia cuneata, Eragrostis eriopoda, Pimelea trichostachya, Brachyscome lineariloba* and *Tetragonia eremaea*.

### *Muehlenbeckia florulenta* open shrubland

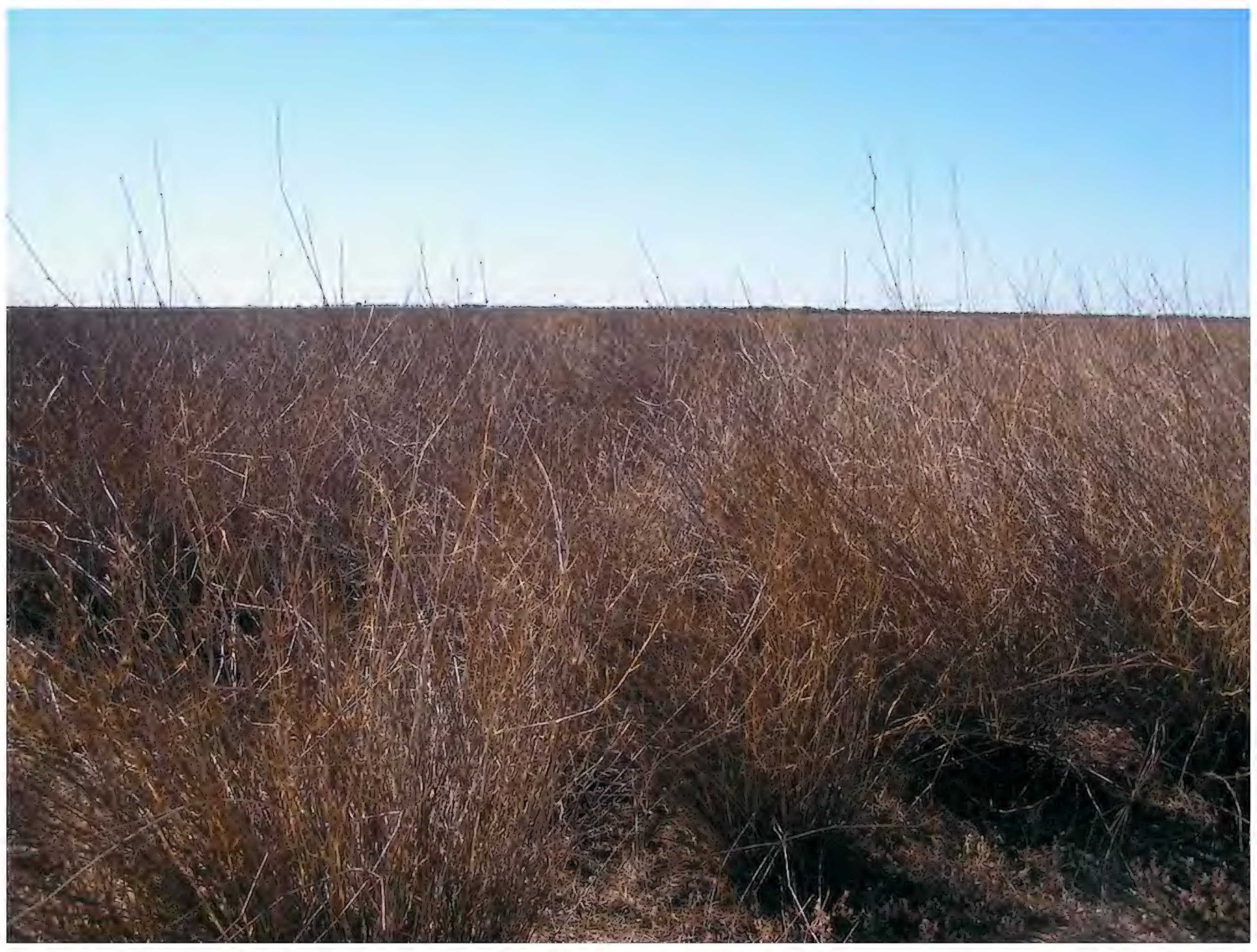

**Fig. 17.** *Muehlenbeckia florulenta* open shrubland

Low open shrubland dominated by *Muehlenbeckia florulenta* (Fig. 17) occurs in low-lying areas associated with the Darling River floodplains and in localised drainage basins. *Eragrostis australasica* is frequently associated and the community may grade into one dominated by that species. Frequently associated shrubs include *Atriplex holocarpa, Sclerolaena muricata* and *Chenopodium nitrariaceum*. Ground layer species include *Senecio runcinifolius, Pycnosorus pleiocephala, Rhodanthe corymbiflora, Ixiolaena leptolepis* and *Agrostis avenacea* var. *avenacea*.

## *Grasslands*

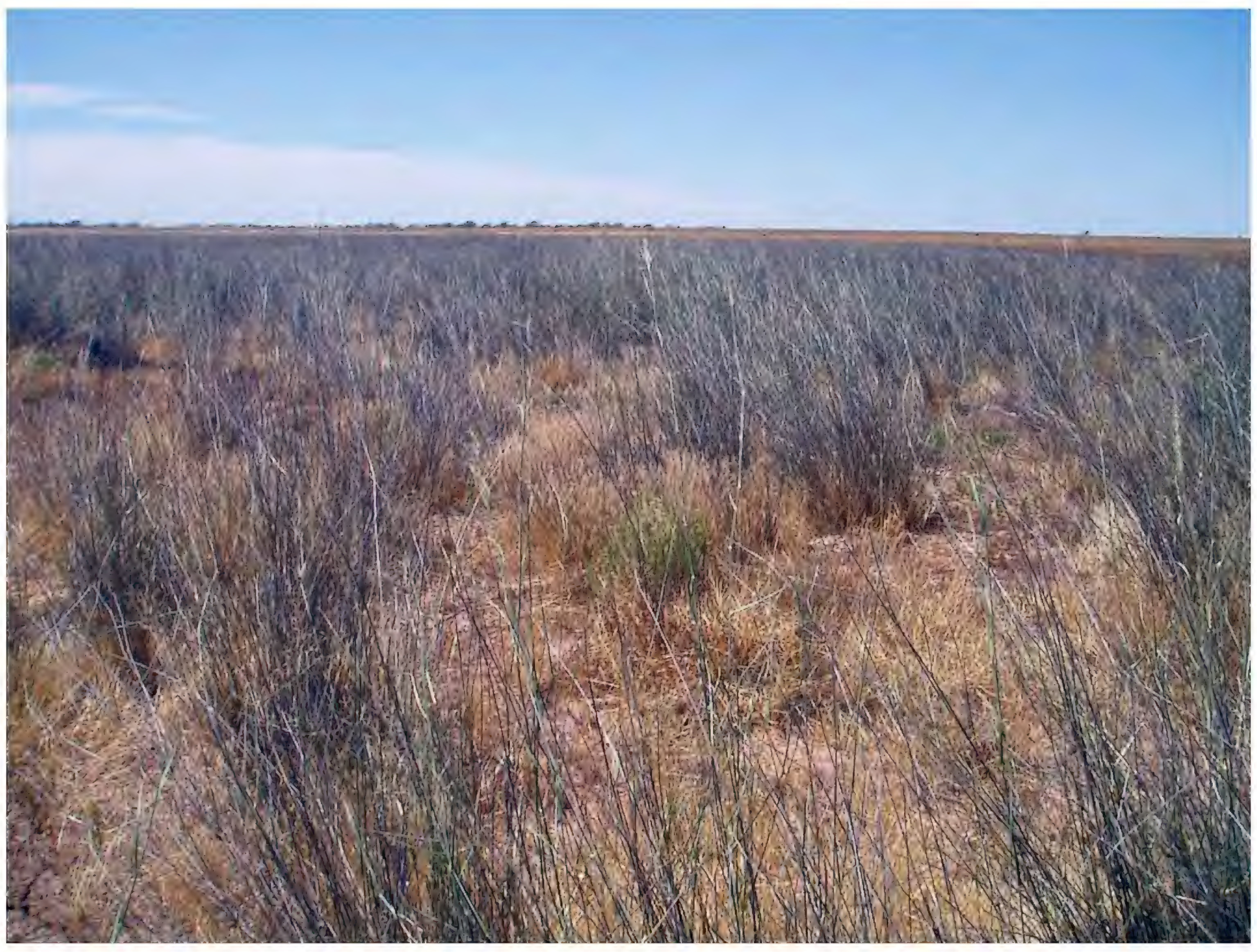

**Fig. 18.** *Eragrostis australasica* grassland

### *Eragrostis australasica* grassland

Areas of *Eragrostis australasica* grassland (Fig. 18) occur in shallow lakes associated with the Darling River floodplain and in relic lakes within sandplains. *Muehlenbeckia florulenta* may be associated and other associated species include *Agrostis avenacea* var. *avenacea*, *Pycnosorus pleiocephala, Plantago drummondii, Chenopodium nitrariaceum, Senecio*

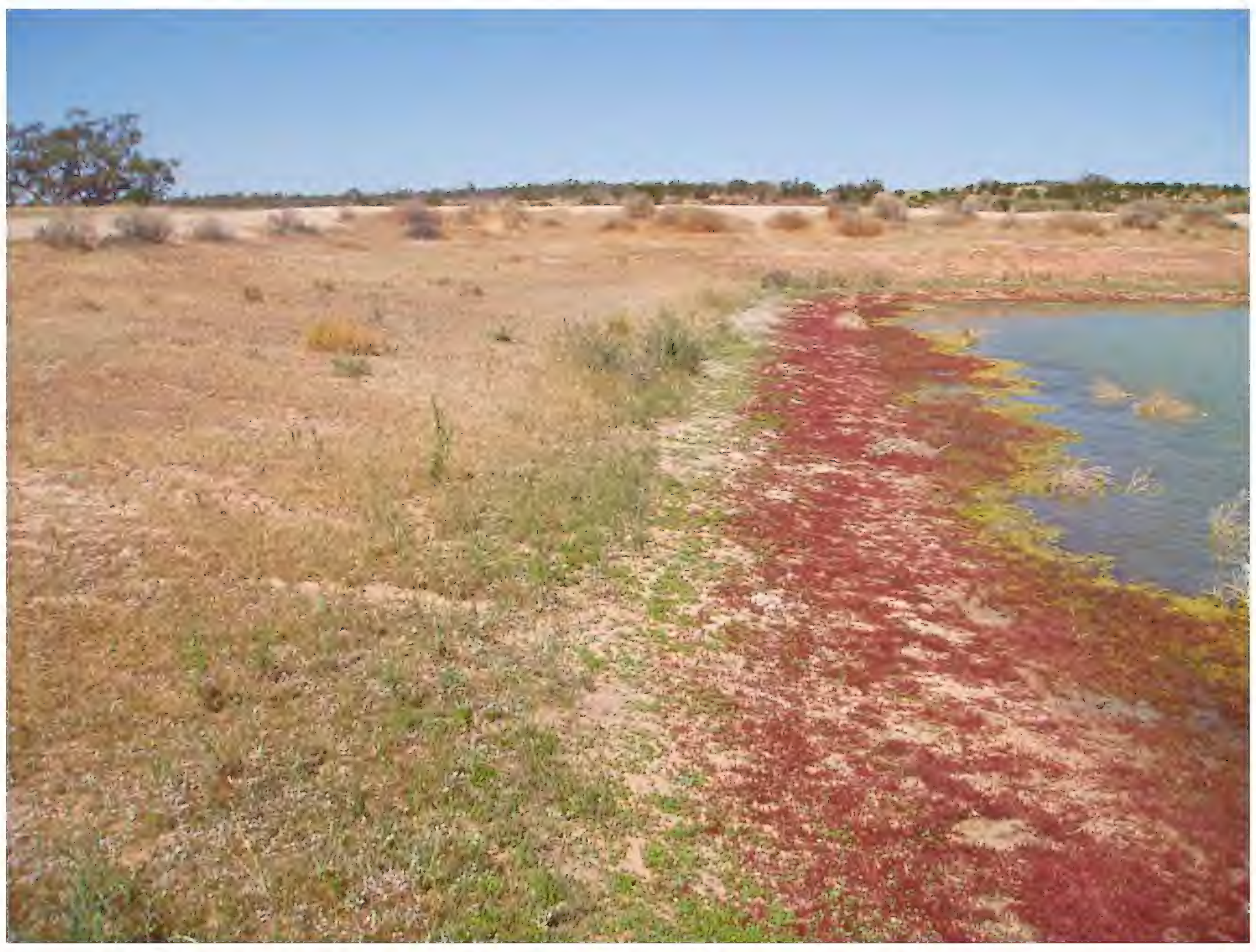

**Fig. 19.** Anthropogenic herbland

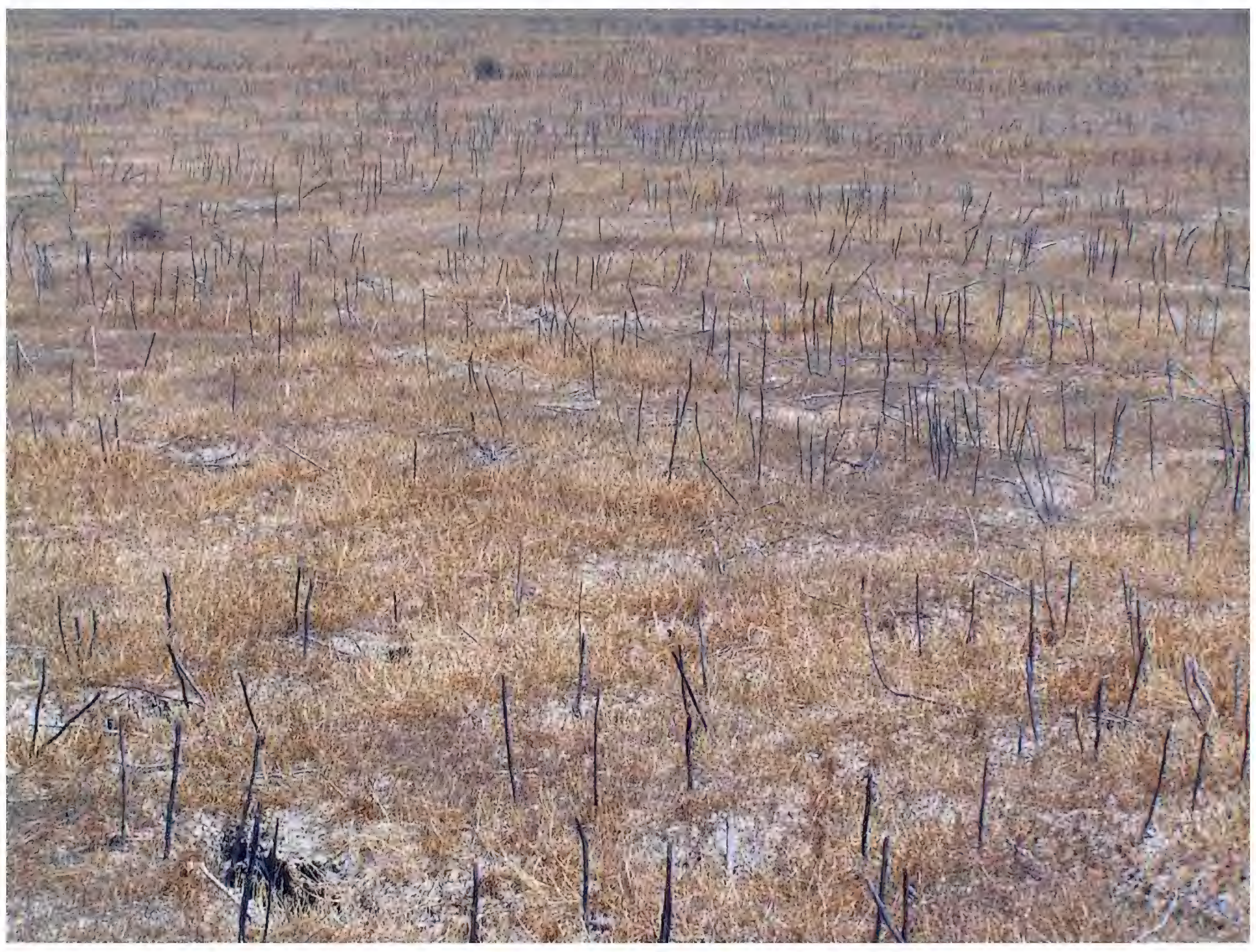

**Fig. 20.** Cropped lakebed

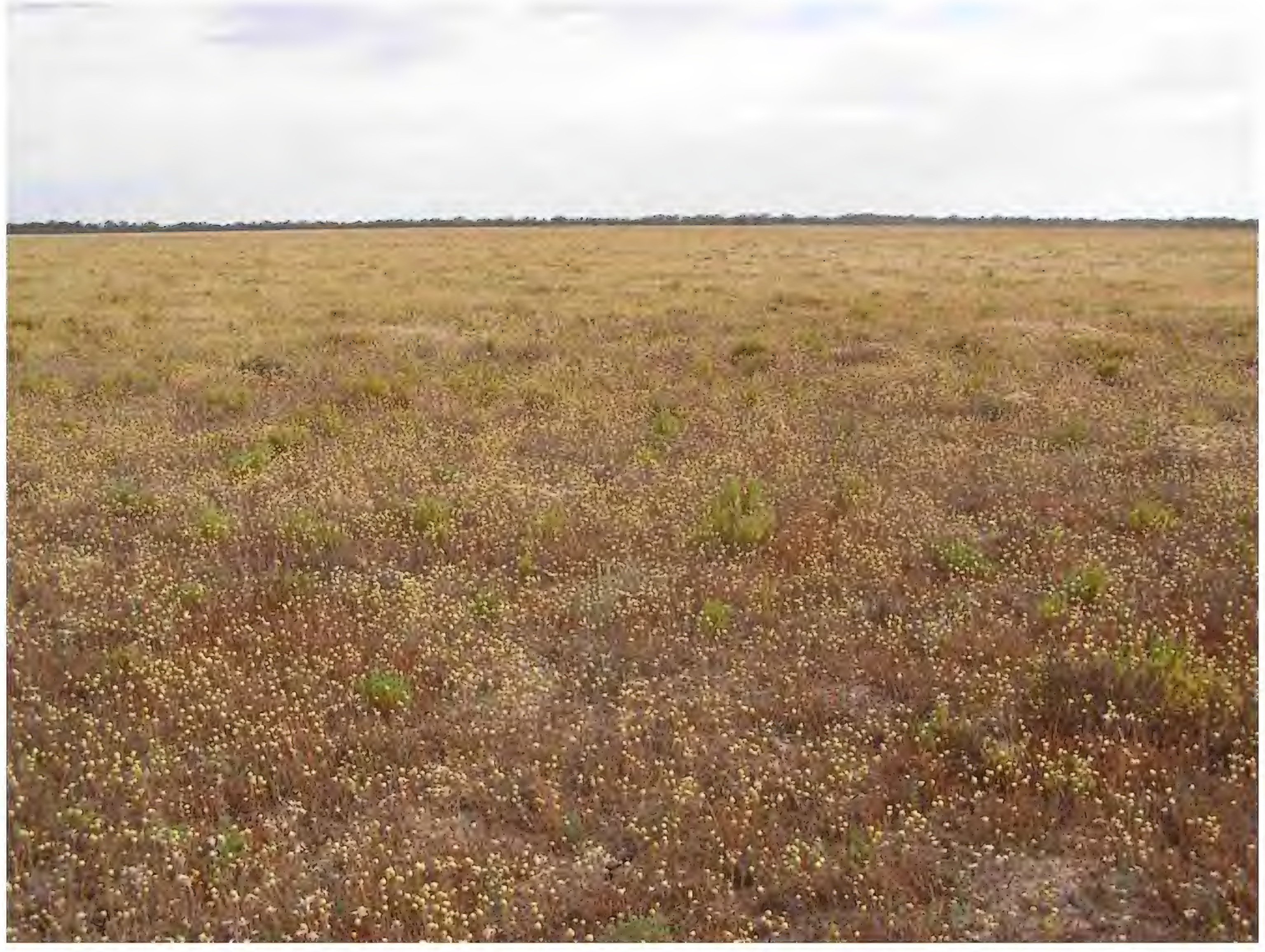

**Fig. 21.** Lakebed herbland

*runcinifolius, Brachyscome lineariloba, Helipterum moschatum, Sclerolaena intricata, Daucus glochidiatus, Eragrostis setifolia, Rumex crystallinus* and *Marsilea drummondii*.

### *Herblands*

#### Anthropogenic herbland

Sites which had been subject to significant disturbance through the pastoral history of the properties, including homestead sites, earth tanks and yards had a predictably, high proportion of weed species (Fig. 19).

#### Cropped lakebed

Areas of the Darling River floodplain including Wongalara Lake have been cropped in the past. At the time of the survey there was little distinguishable vegetation on most of these areas apart from crop residues (Fig. 20). The bed of Lake Poopelloe, which should typically be vegetated by a *Muehlenbeckia florulenta* open shrubland supports remnants of a Safflower (*Carthamus tinctorius*) crop.

#### Lakebed herbland

As the lakes dry out after flooding an annual herbland develops (Fig. 21). This is dominated by *Marsilea drummondii, Centipeda minima, Heliotropium* species,

**Table 4. Sampling intensity, species richness and weediness of vegetation communities of the Mount Murchison and Wilga areas.**

| Vegetation community | No. of quads. | Native species richness | | Introduced species richness | |
|---|---|---|---|---|---|
| | | **Mean** | **Total** | **Mean** | **Total** |
| Woodlands | | | | | |
| *Atalaya hemiglauca* low open woodland | 3 | 17.7 | 42 | 2.3 | 6 |
| *Casuarina pauper / Alectryon oleifolius* low open woodland | 3 | 21.7 | 46 | 2.7 | 5 |
| *Eucalyptus camaldulensis* open woodland | 7 | 12.3 | 42 | 3.6 | 7 |
| *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland | 21 | 13.1 | 95 | 2.7 | 17 |
| *Flindersia maculosa* low open woodland | 9 | 18.4 | 65 | 1.6 | 7 |
| Tall shrublands | | | | | |
| *Acacia aneura* tall open shrubland (plains) | 1 | 33.0 | 33 | 2.0 | 2 |
| *Acacia ligulata* tall open shrubland | 1 | 7.0 | 7 | 3.0 | 3 |
| *Hakea leucoptera* tall open shrubland | 1 | 23.0 | 23 | 7.0 | 7 |
| Low shrublands | | | | | |
| *Acacia victoriae* open shrubland | 5 | 18.0 | 59 | 3.8 | 12 |
| *Atriplex nummularia* open shrubland | 3 | 12.7 | 34 | 1.3 | 4 |
| *Eremophila / Dodonaea* open shrubland | 4 | 21.3 | 52 | 3.8 | 9 |
| *Maireana pyramidata* low open shrubland | 10 | 17.5 | 77 | 1.8 | 10 |
| *Muehlenbeckia florulenta* open shrubland | 18 | 10.8 | 77 | 3.1 | 16 |
| Grasslands | | | | | |
| *Eragrostis australasica* grassland | 5 | 13.2 | 44 | 3.6 | 14 |
| Herblands | | | | | |
| Anthropogenic herbland | 3 | 27.3 | 53 | 11.7 | 25 |
| Cropped lakebed | 2 | 3.5 | 7 | 2.5 | 5 |
| Lakebed herbland | 6 | 9.5 | 47 | 1.5 | 8 |

*Myriophyllum verrucosum, Plantago turrifera, Sclerolaena intricata* and *Pycnosorus pleiocephala*. It is likely that the species composition of these areas is variable and dependant on seasonality of rainfall events, with grasses becoming more prominent following good summer rainfall.

### *Plant species*

A total of 237 vascular plant species from 46 families were recorded during this study of the Mount Murchison and Wilga areas (Appendix 1). Of the plant species recorded from the Park, 37 (15.6%) are introduced. The sampling effort in each vegetation community, mean and total native and introduced species richness is shown in Table 4.

## Discussion

### *Mapping communities*

There are a number of inherent problems in vegetation mapping: vegetation mapping assumes discontinuities between communities which may not exist; the constraints of cartography determine the minimum area that can clearly be distinguished; it is generally not feasible to ground truth the whole of an area and thus parts of the map assume a consistent relationship between the vegetation and other features such as soil type and topography.

Beadle's (1948) map of western NSW at approximately 1:1 000 000 scale includes two units for the area. James's (1960) map of the Paroo-Upper Darling shows three vegetation units and Milthorpe (1991) 1:500 000 map of north western NSW shows five units. Pickard and Norris's (1994) map of north-western NSW shows nine vegetation units. In the attached map at 1:50 000 scale, 16 units are mapped and a further one indicated by point location (Anthropogenic herbland). It was difficult to separate the shrubland communities of the Popelloe landsystem of Wilga. The map suffers from the limitations noted above. The smallest area that could be mapped was 100 metres in width but in the interest of clarity some vegetation types occurring in narrow bands, such as *Eucalyptus camaldulensis* along the Darling River were exaggerated to this width. Similarly some areas remote from tracks may include small patches of another vegetation unit from that mapped.

During the survey over 330 km of driven and walked transects were traversed and, given the association of many vegetation communities with landscape features, boundaries could be drawn with some confidence. With the current technology of mapping enabling changes to be readily incorporated, it is hoped that the map will be refined with following further botanical survey.

**Table 5. Conservation status of communities based on Benson** *et al.* **(2010)**

| Vegetation community | Area (ha) approx | Equivalent Benson et al. (2010) vegetation community I.D | Conservation status (Benson et al. 2010) |
|---|---|---|---|
| Woodlands | | | |
| *Atalaya hemiglauca* low open woodland | 457 | 137 | Near Threatened |
| *Casuarina pauper / Alectryon oleifolius* low open woodland | 1,284 | 58 | Near Threatened |
| *Eucalyptus camaldulensis* open woodland | 491 | 36 | Vulnerable |
| *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland | 13,147 | 37, 38, 40 | Vulnerable (ID 37), Least Concern (ID 38), Endangered (ID 40). Listed as Endangered under the NSW *Threatened Species Conservation Act 1995* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* |
| *Flindersia maculosa* low open woodland | 9,997 | 144 | Near Threatened |
| Tall shrublands | | | |
| *Acacia aneura* tall open shrubland (plains) | 383 | 119 | Near Threatened |
| *Acacia ligulata* tall open shrubland | 1,098 | 124 | Least Concern |
| *Hakea leucoptera* tall open shrubland | 24 | 199 | Near Threatened |
| Low shrublands | | | |
| *Acacia victoriae* open shrubland | 2,658 | 139 | Vulnerable |
| *Atriplex nummularia* open shrubland | 518 | 158 | Endangered |
| *Eremophila / Dodonaea* open shrubland | 4,604 | 143 | Least Concern |
| *Maireana pyramidata* low open shrubland | 16,785 | 153 | Near Threatened |
| *Muehlenbeckia florulenta* open shrubland | 24,001 | 25 | Least Concern |
| Grasslands | | | |
| *Eragrostis australasica* hummock grassland | 483 | 24 | Least Concern |
| Herblands | | | |
| Anthropogenic herbland | 28 | N/A | N/A |
| Lakebed herbland | 3297 | 166 | Least Concern |

### *Distribution of communities*

Floristically, the Mount Murchison and Wilga areas could be considered contiguous if not separated by the Darling River.

The distribution and species composition of vegetation communities within Paroo Darling National Park is largely determined by variation in topography, landform position and soil type. *Eucalyptus* species open woodlands are associated with texture contrast soils of the major creeklines and on clays around the overflow lakes. Woodlands variously dominated by *Casuarina pauper* and *Flindersia maculosa* occur on desert loams and mixed herblands occur on the clays associated with the floodplains of the Darling River. *Maireana pyramidata* low open shrubland occurs on the sandplains. Other factors, notably past grazing history, have also played a role in determining the present distribution and floristic composition of the communities present.

### *Vegetation condition*

Whilst this was not intended to be a detailed assessment of vegetation condition, regeneration of overstorey and perennial understorey species was noted. Species richness and weediness are additional factors which give some measure of vegetation condition. The communities of the Mount Murchison area are overall in good condition despite the history of grazing management. It suggests that this part of the Park has previously been subject to a relatively conservative grazing regime. Grazing pressure for the Wilga area appeared to be elevated towards the homestead and holding paddocks, however it is moderate to low over much of the remaining area.

### *Conservation status of vegetation communities*

The communities mapped largely correspond to those listed by Benson (1989), Benson (2006), Benson (2008) and Benson *et al.* (2010). Table 5 shows the threat category of communities based on Benson *et al.* (2010). Nine of the communities recorded have a threat category of Near Threatened, Vulnerable or Endangered. Benson *et al.* (2010) has allocated threatened categories which are based on a number of sources including the guidelines for nominating ecological communities under the Commonwealth EPBC Act (Benson 2006).

*Eucalyptus coolabah / Eucalyptus largiflorens* open woodland is listed as an endangered ecological community under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the NSW *Threatened Species Conservation Act 1995* (TSC Act). Under the EPBC Act, the community is referred to as Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions and under the TSC Act, the community is referred to as Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion. This endangered ecological community is known to be associated with the following Benson *et al.* (2010) vegetation communities:

> Black Box woodland on NSW central and northern floodplains including the DRP and BBS Bioregions (ID No. 37);
>
> Coolabah – River Coobah – Lignum woodland of frequently flooded floodplains mainly in the Darling Riverine Plains Bioregion (ID No. 39); and
>
> Coolabah open woodland with chenopod/grassy ground cover on grey and brown clay floodplains (ID No. 40).

The Benson *et al.* (2010) threat categories for these vegetation communities associated with the endangered ecological community are outlined in Table 5. Keith et al. (2009) determined that around 60% of the community had been lost since European settlement and that the rate of loss had increased in recent years. That which remains is increasingly fragmented (NFRPC 2004). Further to clearing other key threats to the endangered ecological community include hydrological changes and altered water flow and flooding regimes (including inundation duration), inappropriate grazing regimes and invasion by weeds (Benson 2006; Benson 2008; Benson *et al.* 2010; TSSC 2011; Keith et al. 2009). A major threat to the *Eucalyptus camaldulensis* open woodland community, a related floodplain community, has been and continues to be also a reduction in flooding regimes (Benson 2006; Benson 2008; Benson *et al.* 2010).

Almost all of the communities recorded for Mount Murchison and Wilga are susceptible to and threatened by grazing pressure (Benson 2006; Benson 2008; Benson *et al.* 2010). Grazing threatens the regeneration of many palatable plant species associated with these communities which ultimately alters the floristic diversity and structure of the community (Benson 2006; Benson 2008; Benson *et al.* 2010). There is general concern for communities such as *Casuarina pauper / Alectryon oleifolius* low open woodland (Westbrooke 2005; Benson 2006), *Hakea leucoptera* tall open shrubland (Westbrooke 1998),*Atalaya hemiglauca* low open woodland, , *Eucalyptus coolabah / E. largiflorens* open woodland, *Acacia aneura* tall open shrubland, and *Acacia ligulata* tall open shrubland occurs (Benson 2006; Benson 2008; Benson *et al.* 2010)and for example where key species may die off unless recruitment. A number of these woodland communities such as *Atalaya hemiglauca* low open woodland, *Casuarina pauper / Alectryon oleifolius* low open woodland, *Flindersia maculosa* low open woodland and *Hakea leucoptera* tall open shrubland are regarded as near threatened largely due to past timber harvesting/thinning/clearing and lack of regeneration (Benson *et al.* 2010). *Atalaya hemiglauca* low open woodland may become vulnerable if recruitment of key species does not occur (Benson *et al.* 2010). *Acacia victoriae* open shrubland is likely to be a derived community as a result of the *Callitris* being removed in the past from timber cutting (Benson *et al.* 2010). *Callitris glaucophylla* seedlings are known to be intolerant of grazing, palatable and very slow growing in the early stages (Westbrooke 1998) which may partly explain why following this disturbance, there is a lack of recruitment and a gradual loss of this species from this community.

*Atriplex nummularia* open shrubland is considered endangered (Benson *et al.* 2010) however the formal status of this community remains unresolved in NSW.. The presence of these vegetation communities on Mount Murchison and Wilga areas of Paroo-Darling National Park has made a significant contribution to conservation of plant communities in NSW.

### *Plant species*

Two hundred and thirty seven species of vascular plants were recorded during this study. As noted, this survey, undertaken following three years of severe drought, whilst the winter rains meant that a range of herbs and grass were recorded, it is likely that many more species are still to be recorded.

The highest representation of these species recorded for the Mount Murchison and Wilga areas was from the family Chenopodiaceae (45).

The highest levels of occurrence of introduced species were in communities subject to the greatest influence from water and disturbance. These include the Anthropogenic herblands around earth tanks. This is in accord with Westbrooke (1990) who found a high negative correlation between occurrence of introduced species and distance from water in studies at Mallee Cliffs National Park and Nanya Station.

### *Rare, threatened or restricted species*

None of the species recorded during this study are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) or the *Threatened Species Conservation Act 1995* (NSW).

## Conclusion

The Mount Murchison and Wilga blocks of Paroo Darling National Park are a significant component of the New South Wales Park estate. The area is important for protecting a range of vegetation communities which are under threat from continued rangeland grazing in unprotected areas. This study provides valuable baseline data to aid park managers in prioritising actions to facilitate the recovery of the vegetation from past use and the protection of biodiversity values.

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## References

Beadle, N.C.W. (1945). *Vegetation Map of Western New South Wales*. Soil Conservation Service, Sydney.

Beadle, N.C.W. (1948). *The Vegetation and Pastures of Western New South Wales with Special Reference to Soil Erosion*. Government Printer, Sydney.

Benson, J. (1989). Establishing priorities for the conservation of rare or threatened plants and plant associations in New South Wales. In: *The Conservation of Threatened Species and Their Habitats – Occasional Paper No. 2: 17-82*. Eds. M. Hicks and P. Eiser. Australian Committee for IUCN, Canberra.

Benson, J. S. (2006) New South Wales vegetation classification and assessment: Introduction – the classification, database, assessment of protected areas and threat status of plant communities. *Cunninghamia* 9(3): 331-382.

Benson, J. S., Allen, C. B., Togher, C. and Lemmon, J. (2006) New South Wales vegetation classification and assessment: Part 1 plant communities of the NSW Western Plains. *Cunninghamia* 9(3): 383- 450.

Benson, J. (2008). New South Wales Vegetation classification and Assessment: Part 2 Plant communities of the NSW South-western Slopes Bioregion and update of NSW Western Plains plant communities, Version 2 of the NSWVCA database. *Cunninghamia*, 10(4): 599–673.

Benson, J.S., Richards, P., Waller, S. and Allen, C. (2010). New South Wales Vegetation classification and Assessment: Part 3 Plant communities of the NSW Brigalow Belt South, Nandewar and west New England Bioregions and update of NSW Western Plains and South-western Slopes plant communities, Version 3 of the NSWVCA database. *Cunninghamia* 11(4).

Clewett, J. F., Clarkson, N. M., Owens, D. T. and Abrecht, D. G. (1994). *Australian Rainman: Rainfall Information for Better Management.* Department of Primary Industries, Brisbane.

Edwards, K. (1979). *Rainfall in New South Wales - With Special Reference to Soil Conservation - Technical Handbook No. 3.* Soil Conservation Service of New South Wales, Sydney.

Hardy, B. (1969). *West of the Darling*. Rigby, Adelaide.

Hazelton, P. (1977). *Wilcannia Land Systems Series Sheet SH 54-16*. New South Wales, Soil Conservation Service.

Heathcote, R. L. (1965). *Back of Bourke: A Study of Land Appraisal and Settlement in Semi-arid Australia*. Melbourne University Press, Carlton.

Hercus, L. (1993). *Paakantyi Dictionary*. Published with the assistance of AIATSIS, Canberra.

Hope, J. and Lindsay, R. (2010). *The people of the Paroo River*. Department of Environment, Climate Change and Water NSW, Sydney.

Hunter, J. and Fallavollita, E. (2003). *Vegetation and Floristics of Paroo Darling National Park - Thilta Karra Section*. Report to the New South Wales National Parks and Wildlife Service.

James, J. W. (1960). Erosion survey of the Paroo-Upper Darling region. Part III. *Journal of Soil Conservation Service of NSW* 16: 185-206.

Jervis, J. (1948). The west Darling country: its exploration and development. *Royal Australian Historical Society* 34: 65-88.

Kershaw, K. A. and Looney, J. H. H. (1985). *Quantitative and Dynamic Plant Ecology*. Edward Arnold, Caufield East, Victoria.

Keith DA, Orscheg C, Simpson CC, Clarke PJ, Hughes L, Kennelly SJ, Major RE, Soderquist TR, Wilson AL, Bedward M (2009) A new approach and case study for estimating extent and rates of habitat loss for ecological communities. *Biological Conservation* **142,** 1469-1479.

Knight, R. (1994). *Flora, Fauna and Wilderness Values of the Mount Glass and Peery Lake areas, Western New South Wales*. Report by the Wilderness Society to the Australian Heritage Commission, Sydney.

Lembit, R. (1993). *NSW Wilderness Review Stage II - Wilderness Area Investigation, Peery Lake and Mount Glass Study Areas - Botanical Survey Report*. Report to the Wilderness Society, Sydney.

Milthorpe, P. L. (1991). Vegetation. In: *Lands of the North-West Corner of NSW – Technical Report No. 12.* Ed. P.L. Milthorpe, Soil Conservation Service of NSW.

NFRPC, (2004). Vegetation Communities of the Northern Floodplains Western New South Wales Books 1–3: Walgett, Brewarrinna and Bourke Shires. Northern Floodplains Regional Planning Committee.

NPWS (2000). *File F/2835/vol. III - Peery*. New South Wales National Parks and Wildlife Service.

NPWS (2002). *File 02-00269*. New South Wales National Parks and Wildlife Service.

Pickard, J. and Norris, E. H. (1994). The natural vegetation of north-western New South Wales: notes to accompany the 1:1 000 000 vegetation map sheet. *Cunninghamia* 3(3): 423-464.

Pickard, J. (1990). Analysis of stocking records from 1884 to 1988 during the subdivision of Momba, the largest property in semi-arid New South Wales. *Proceedings of the Ecological Society of Australia* 16: 245-253.

Specht, R. L. (1970). Vegetation. In: *The Australian Environment*. Ed. G. W. Leeper. Melbourne University Press, Melbourne.

Stanley, R. J. (1991). Land settlement and development. In: *Lands of the North-West Corner of NSW - Technical Report No. 12*. Ed. P. L. Milthorpe. Soil Conservation Service of NSW.

TSSC (2011). *Conservation advice for the Coolibah – Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions ecological community*. Threatened Species Scientific Committee.

Walker, P. (1972). *Barnato Land Systems Series Sheet SH 55-13*. New South Wales, Soil Conservation Service.

Westbrooke, M. E. (1990). Effects of grazing pressure on weediness in mallee communities: studies at Mallee Cliffs National Park and Nanya Station, south-western New South Wales. In: *The Mallee Lands: A Conservation Perspective*. Eds J. C. Noble, P. J. Joss and G.K. Jones. CSIRO, Melbourne.

Westbrooke, M. E. (1998). *The ecology and regeneration status of Belah woodlands in south-eastern Australia*. PhD Thesis. Department of Botany. School of Life Sciences. Faculty of Science, Technology and Engineering. LaTrobe University. Bundoora, Victoria.

Westbrooke, M.E. (2005). Relationship between perennial species richness and distance from water in *Casuarina pauper* (Belah) woodland. *Victorian Naturalist,* **122**: 57-62

Westbrooke, M., Gowans, S. and Gibson, M. (2011). The vegetation of the Coonavitra area, Paroo Darling National Park, western New South Wales. *Cunninghamia* 12 (1): 7-27.

Westbrooke, M., Gowans, S., Gibson, M., Callister, K., Palmer, G., Florentine, S., O'Keefe, M., Warnock, A. and Grundell, R. (2006a). *The Vegetation of the Coonavitra area, Paroo Darling National Park, Western New South Wales*. Report prepared for the New South Wales National Parks and Wildlife Service by the Centre for Environmental Management, University of Ballarat.

Westbrooke, M., Gowans, S., Gibson, M., Callister, K., Palmer, G., Florentine, S., O'Keefe, M., Warnock, A. and Grundell, R. (2006b). *The Vegetation of the Mount Murchison and Wilga areas, Paroo Darling National Park, Western New South Wales*. Report prepared for the New South Wales National Parks and Wildlife Service by the Centre for Environmental Management, University of Ballarat.

Westbrooke, M., Leversha, J., Gibson, M., Milne, R., Gowans, S., Harding, C., Callister, K. and O'Keefe, M. (2002). *The Vegetation of Peery National Park Western New South Wales*. Report prepared for the New South Wales National Parks and Wildlife Service by the Centre for Environmental Management, University of Ballarat, Victoria.

Westbrooke, M., Leversha, J., Gibson, M., O'Keefe, M., Milne, R., Gowans, S., Harding, C. and Callister, K. (2003). The vegetation of Peery Lake area, Paroo-Darling National Park, western New South Wales. *Cunninhamia* 8(1): 111-128.

Young, M.D., Gibbs, M., Holmes, W.E. and Mills, D.M.D. (1984). Socio-economic influences on pastoral management. In: Harrington, G.M., Wilson, A.D. and Young, M.D. eds. *Management of Australia's Rangelands*. CSIRO, Melbourne.

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## Appendix 1. Flora species recorded within the Mount Murchison and Wilga areas with frequency (%) of occurrence in communities

Nomenclature is according to Harden (1990-1993). * denotes introduced species.

### Vegetation communities

#### Woodlands

1 *Atalaya hemiglauca* open woodland
2 *Casuarina pauper / Alectryon oleifolius* low open woodland
3 *Eucalyptus camaldulensis* open woodland
4 *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland
5 *Flindersia maculosa* low open woodland

#### Tall shrublands

6 *Acacia aneura* tall open shrubland (plains)
7 *Acacia ligulata* tall open shrubland
8 *Hakea leucoptera* tall open shrubland

#### Low Shrublands

9 *Acacia victoriae* open shrubland
10 *Atriplex nummularia* open shrubland
11 *Eremophila / Dodonaea* open shrubland
12 *Maireana pyramidata* low open shrubland
13 *Muehlenbeckia florulenta* open shrubland

#### Grasslands

14 *Eragrostis australasica* hummock grassland

#### Herblands

15 Anthropogenic herbland
16 Cropped lakebed
17 Lakebed herbland

| | **Vegetation communities** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxon, family and name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
| **Number of quadrats** | **3** | **3** | **7** | **21** | **9** | **1** | **1** | **1** | **5** | **3** | **4** | **10** | **18** | **5** | **3** | **2** | **6** |
| **FERNS** | | | | | | | | | | | | | | | | | |
| **Marsileaceae** | | | | | | | | | | | | | | | | | |
| *Marsilea drummondii* | | | | 10 | | 100 | | | 20 | 33 | | | 17 | 40 | | | 17 |
| *Marsilea* spp. | | | | | | | | | | | | | | 20 | | | |
| **MONOCOTYLEDONS** | | | | | | | | | | | | | | | | | |
| ***Amaryllidaceae*** | | | | | | | | | | | | | | | | | |
| *Crinum flaccidum* | 33 | | | | | | | | 20 | | | | | | | | |
| **Asphodelaceae** | | | | | | | | | | | | | | | | | |
| *Bulbine alata* | | | | 5 | | 100 | | | 20 | | | 10 | | | 33 | | |
| *Bulbine bulbosa* | | | | 10 | 22 | | | | | | | 10 | | | | | |
| *Bulbine* spp. | | | | | | | | | | 33 | | | | | | | |
| **Cyperaceae** | | | | | | | | | | | | | | | | | |
| *Isolepis congrua* | | | | | | | | | | | | | | | 33 | | |
| *Isolepis* spp. | | | | | | | | | | | | | | | 33 | | |
| **Poaceae** | | | | | | | | | | | | | | | | | |
| *Agrostis avenacea* var. *avenacea* | | 33 | | 5 | | | | | 20 | 33 | | | 33 | 80 | 33 | | 17 |
| *Austrostipa nitida* | | | | | 11 | 100 | | | | | | | | | | | |
| *Austrostipa nodosa* | | | | 5 | | | | | | | | | 6 | | | | |
| *Austrostipa scabra* | 100 | 67 | | 5 | 100 | | | 100 | 60 | 33 | 100 | 90 | 11 | | | | 17 |
| *Austrostipa* spp. | | | | | 11 | | | | 20 | | | | 6 | | | | |

| | Vegetation communities | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxon, family and name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
| **Number of quadrats** | **3** | **3** | **7** | **21** | **9** | **1** | **1** | **1** | **5** | **3** | **4** | **10** | **18** | **5** | **3** | **2** | **6** |
| *Brachyachne ciliaris* | | | | | 11 | | | | | | | | | | | | |
| *Bromus arenarius* | | | | 5 | | | | | | | | | | | | | |
| *Chloris truncata* | | | | | 11 | | | | | | | | | | 33 | | |
| *Enneapogon* spp. | | | | | | | | | | | | 10 | | | | | |
| *Enteropogon acicularis* | | 33 | | | | | | | | | 25 | | | | | | |
| *Eragrostis australasica* | | | 14 | 5 | | | | 100 | | 33 | | | | 100 | | | 17 |
| *Eragrostis dielsii* | | | | | | | | | | | | | | | | | 17 |
| *Eragrostis eriopoda* | 33 | | | | | 100 | | | 20 | 33 | | 40 | 6 | 20 | | | |
| *Eragrostis setifolia* | | | | 5 | | | | | | | | 10 | 11 | 40 | 33 | | |
| *Eragrostis* spp. | | 33 | | 5 | 11 | | | 100 | | | | | 6 | | 67 | | |
| * *Hordeum leporinum* | | | 14 | 14 | | | | 100 | 40 | | | | 39 | 20 | 33 | 50 | 17 |
| *Monachather paradoxa* | | | | | 22 | | | | | | | | | | | | |
| * *Schismus barbatus* | 67 | 33 | 43 | 48 | 33 | | 100 | 100 | 20 | 33 | 50 | 20 | 11 | 60 | 67 | | 17 |
| **DICOTYLEDONS** | | | | | | | | | | | | | | | | | |
| **Aizoaceae** | | | | | | | | | | | | | | | | | |
| *Tetragonia eremaea* | 33 | 67 | 57 | 19 | 67 | | | | 40 | 33 | | 40 | | | 33 | | 17 |
| *Tetragonia* spp. | | | | | | | | | | | | 10 | | | | | |
| *Tetragonia tetragonoides* | | 33 | | | 11 | | | | | | | | | | | | |
| **Amaranthaceae** | | | | | | | | | | | | | | | | | |
| *Alternanthera nodiflora* | | | | 5 | | | | | | | | | | 20 | | | |
| *Alternanthera* spp. | | | | | | | | | | | | | | | | | 17 |
| *Ptilotus nobilis* var. *nobilis* | | | | 5 | | | | | | | | | | | | | |
| **Apiaceae** | | | | | | | | | | | | | | | | | |
| *Daucus glochidiatus* | 67 | | 29 | 14 | 22 | | | | 40 | 33 | 50 | 30 | 22 | 40 | 100 | | |
| *Eryngium plantagineum* | | | | 5 | | | | | 20 | | | | 17 | | | | |
| *Hydrocotyle trachycarpa* | | | | | | | | | | | 25 | | | | | | |
| **Asclepiadaceae** | | | | | | | | | | | | | | | | | |
| *Leichardtia australis* | 33 | | | | | | | | | | | 10 | | | | | |
| **Asteraceae** | | | | | | | | | | | | | | | | | |
| *Brachyscome ciliaris* | | | | | | | | | | | 25 | 10 | | | | | |
| *Brachyscome lineariloba* | 67 | 33 | | 19 | | 100 | | 100 | 60 | | 75 | 40 | 11 | 40 | | | |
| *Brachyscome* spp. | | | | | | | | | 20 | | | 10 | 6 | 20 | | | |
| *Bracteantha bracteata* | | | 14 | | | | | | | | | 10 | | | | | |
| *Calotis erinacea* | | | | | 11 | | | | | | | | | | | | |
| *Calotis hispidula* | | | | | 11 | | | | 20 | | | 30 | | 20 | 33 | | |
| *Calotis multicaulis* | | | | 5 | | | | | | | | 10 | | | | | |
| *Calotis plumulifera* | | | 14 | | | | | | | | | | | | | | |
| *Calotis* spp. | | 33 | | | | | | 100 | 20 | | 25 | 10 | | | 33 | | |
| * *Carthamus lanatus* | | | | | | | | | | | | 10 | | | 33 | | 17 |
| * *Centaurea melitensis* | | 67 | 86 | 19 | | 100 | | | 60 | | 25 | 20 | 17 | 20 | 67 | | |
| *Centipeda cunninghamii* | | 33 | | 5 | | | | | 20 | | | | 6 | 20 | 67 | | 17 |
| *Centipeda minima* | | | | | | | | | | 33 | | | | 20 | | | 17 |
| *Chrysocephalum apiculatum* | | | | 5 | 22 | | | | | | | | | | | | |
| *Chthonocephalus pseudevax* | | | | | 11 | | | | | | | | | | | | |
| *Craspedia alba* | | | | | | | | | | | | | | | | 50 | |
| *Craspedia* spp. | 33 | | | | | | | | | | | 10 | | | | | |
| *Euchiton sphaericus* | | | | | | | | | | | | | 6 | | | | |
| *Gnephosis foliata* | 33 | 100 | | 5 | 78 | 100 | | | | | | 30 | | | 33 | | |
| * *Hedypnois rhagadioloides* subsp. *cretica* | | | | 5 | | | | 100 | 40 | | 50 | | 11 | | 33 | | |
| *Helipterum moschatum* | | | | 5 | 11 | | | | | | | 10 | | 40 | | | 17 |
| * *Hypochaeris glabra* | | | | | 11 | 100 | | | | | | | | | | | |
| *Ixiolaena leptolepis* | | | | | | | | | 20 | 33 | 25 | 20 | 33 | 20 | 33 | | 17 |
| *Ixiolaena tomentosa* | | | | | | 100 | | | | | | 10 | | | 33 | | |
| * *Lactuca saligna* | | | | 5 | | | | | | | | | | | | | |
| *Minuria leptophylla* | | | | | | 100 | | | | | | | | | | | |
| *Myriocephalus stuartii* | 33 | | 14 | | 22 | | 100 | | 40 | | 75 | 10 | 6 | | | | |
| *Pseudognaphalium luteoalbum* | 33 | | | 10 | | 100 | | | 20 | | 25 | | 6 | 20 | 67 | | 17 |
| *Pycnosorus globosus* | | | | | | 100 | | | | | | | | | | | |
| *Pycnosorus pleiocephala* | | 33 | | 29 | | | | 100 | 60 | 33 | 75 | 60 | 44 | 60 | 100 | | 50 |
| *Pycnosorus pleiocephalus* | | | | | | | | | | | | | | | | | 17 |
| * *Reichardia tingitana* | | | | 10 | | | | | | | | | 11 | | | | |
| *Rhodanthe corymbiflora* | 67 | 100 | | 38 | 67 | 100 | | 100 | 60 | 67 | 50 | 100 | 33 | 60 | 100 | 50 | 33 |
| *Rhodanthe floribunda* | | | | | | | | | 20 | | | | 17 | 20 | | | |
| *Rhodanthe uniflora* | | | | 5 | | | | | | | | | | | 33 | | |
| *Senecio glossanthus* | | | | 5 | | | | | | | | | 17 | | | 50 | |
| *Senecio lautus* subsp. *dissectifolius* | | | 14 | | | | | | | | | | | | 67 | | |
| *Senecio quadridentatus* | | | | | | | | | | | | | 6 | | | | |
| *Senecio runcinifolius* | | | 57 | 33 | | | 100 | | | | | | 61 | 40 | | | |
| *Senecio* spp. | | 33 | 14 | 5 | | | | | | 33 | | | | 20 | | | 17 |
| * *Sonchus asper* subsp. *glaucescens* | | | | | | | | | | | | | | | 33 | | |
| * *Sonchus oleraceus* | | | 57 | 14 | 11 | | | 100 | | | 25 | | 33 | 40 | | | |
| *Sonchus* spp. | | | | 10 | | | | | | | | | | | | | |
| *Vittadinia cuneata* | | 33 | | 19 | 44 | | | | | | | 40 | | | 33 | | |
| *Vittadinia* spp. | | | | | 11 | | | | | | | 10 | | | | | |
| *Waitzia acuminata* | | 33 | | | | | | | | | | | | | | | |
| *Xanthium occidentale* | | | | | | | | | | | | | | | 33 | | |

| | | Vegetation communities | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Taxon, family and name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
| | **Number of quadrats** | **3** | **3** | **7** | **21** | **9** | **1** | **1** | **1** | **5** | **3** | **4** | **10** | **18** | **5** | **3** | **2** | **6** |
| * | *Xanthium spinosum* | | | | | | | | | | | | | | | 33 | | |
| | **Boraginaceae** | | | | | | | | | | | | | | | | | |
| * | *Echium plantagineum* | | | | | | | | | | | 25 | | | | 67 | | |
| | *Heliotropium europaeum* | | | | | | | | | | | | | 6 | | 33 | | |
| | *Heliotropium* spp. | | | | | | | | | | 33 | | | | | 33 | | 33 |
| * | *Heliotropium supinum* | | | | | | | | | | | | | | | 33 | | 17 |
| | *Omphalolappula concava* | 33 | | | | 22 | | | | | | | 10 | | | | | |
| | **Brassicaceae** | | | | | | | | | | | | | | | | | |
| * | *Alyssum linifolium* | | | | 10 | 33 | | | 100 | | | | 20 | 56 | 20 | | 50 | |
| | *Arabidella trisecta* | | 33 | | | | 100 | | | | | | 10 | | | | | |
| * | *Brassica* spp. | | | | | | | | | | | | | | 20 | | | |
| * | *Brassica tournefortii* | 33 | | 29 | 24 | | | 100 | 100 | 80 | | 100 | | 28 | | 100 | | 17 |
| * | *Carrichtera annua* | 33 | | | 14 | | | | | 20 | | | 10 | 6 | | 33 | | |
| | *Harmsiodoxa blennodioides* | 33 | | | | | | | | | | | | | | | | |
| | *Harmsiodoxa brevipes* var. *brevipes* | | | | | | 100 | | | | 33 | 25 | | | | | | |
| | *Lepidium hyssopifolium* | | | | | 11 | | | | 20 | | | | | | | | |
| | *Lepidium muelleri-ferdinandii* | | | | 10 | | 100 | | | | | | 10 | | | | | |
| | *Lepidium oxytrichum* | 33 | 67 | | | | | | | | | 25 | | | | 33 | | |
| | *Lepidium papillosum* | | | | 5 | 11 | | | | | | | | 6 | | | | |
| | *Lepidium pseudohyssopifolium* | | 33 | 14 | 14 | | 100 | | | | 33 | | 10 | 17 | 20 | 67 | | 33 |
| | *Lepidium* spp. | | | 14 | 14 | | | | | | | | 20 | 6 | | | | |
| * | *Sisymbrium erysimoides* | 33 | 67 | 100 | 81 | 44 | | | 100 | 20 | 33 | 25 | 10 | 50 | 20 | 100 | | 17 |
| * | *Sisymbrium irio* | | | | 5 | | | | | 20 | | | | 6 | | 33 | | |
| | *Stenopetalum lineare* | | | | | 67 | | | 100 | | 33 | | 30 | | | | | |
| | **Caesalpiniaceae** | | | | | | | | | | | | | | | | | |
| | *Senna form taxon ‘artemisioides’* | | | | | | | | | | | 25 | | | | | | |
| | *Senna form taxon ‘filifolia’* | 33 | | | | | | | | | | 25 | | | | | | |
| | *Senna form taxon ‘petiolaris’* | | | | | | | | | | | 50 | | | | | | 17 |
| | *Senna form taxon ‘zygophylla’* | 33 | | | | | | | | | | | | | | | | |
| | **Campanulaceae** | | | | | | | | | | | | | | | | | |
| | *Wahlenbergia communis* | | | | | | | | | | | | | | | 33 | | |
| | *Wahlenbergia gracilis* | | | | | | | | | 20 | | | 20 | 6 | | 33 | | |
| | *Wahlenbergia* spp. | | | 14 | 5 | 11 | | | 100 | | | 25 | 20 | 6 | 20 | | | |
| | **Caryophyllaceae** | | | | | | | | | | | | | | | | | |
| * | *Spergularia rubra* | | | | 5 | | | | | 20 | | | | | 40 | 67 | | 33 |
| | **Casuarinaceae** | | | | | | | | | | | | | | | | | |
| | *Casuarina pauper* | | 100 | | | 22 | | | | | | | | | | | | |
| | **Chenopodiaceae** | | | | | | | | | | | | | | | | | |
| | *Atriplex angulata* | | | | 5 | 11 | | | | 20 | | | 10 | | | | | 17 |
| | *Atriplex eardleyae* | | | 14 | 19 | | | | | | | 25 | | 28 | 20 | 100 | | |
| | *Atriplex holocarpa* | 33 | 100 | | 24 | 56 | | | | | 33 | | 50 | 50 | 20 | 100 | 50 | 50 |
| | *Atriplex leptocarpa* | | | 43 | 19 | | | | | | | | | | 20 | | | |
| | *Atriplex limbata* | 33 | | 14 | 5 | 22 | | | 100 | 20 | | 25 | 30 | 6 | | | | 17 |
| | *Atriplex lindleyi* | | 33 | | 14 | | | | | | | 25 | | 22 | 20 | | | 17 |
| | *Atriplex nummularia* | | 33 | | 5 | | | | | | 100 | | | 11 | | 33 | | |
| | *Atriplex pseudocampanulata* | | | | 5 | | | | | | | | | | | | | |
| | *Atriplex semibaccata* | | | | 5 | | | | | | | | | 6 | | | | |
| | *Atriplex* spp. | 67 | | | 10 | | | | | 20 | | | | 11 | | 33 | | |
| | *Atriplex stipitata* | | | | 14 | | | | 100 | 20 | | 75 | | | | | | 17 |
| | *Chenopodium auricomum* | | | 14 | | | | | | | | | | 11 | | | | |
| | *Chenopodium cristatum* | | | | 14 | 11 | | | | | | | | 17 | 20 | | 50 | 17 |
| | *Chenopodium curvispicatum* | 67 | 100 | | 19 | 56 | 100 | | | | | | 40 | | | | | |
| | *Chenopodium desertorum* | | | 14 | 5 | | | | | | | | | | | | | |
| | *Chenopodium melanocarpum* | | | | | 11 | | | | | | | | | | | | |
| * | *Chenopodium murale* | | | | | | | | | | | | | | | 33 | | |
| | *Chenopodium nitrariaceum* | | | 71 | 67 | | | | | 20 | 67 | | | 39 | 40 | 67 | | |
| | *Chenopodium pumilio* | | | | | 11 | | | | | | | | | | | | |
| | *Chenopodium* spp. | | | | | | | | | | | | | 6 | | | | |
| | *Dissocarpus paradoxus* | | | 14 | 14 | 67 | 100 | | | | 33 | | 50 | 6 | | | | |
| | *Einadia nutans* | 33 | 33 | 71 | 67 | 11 | 100 | | | 60 | | 75 | | 6 | | 33 | | |
| | *Enchylaena tomentosa* | | 67 | 86 | 62 | 67 | 100 | 100 | | 40 | | 100 | | | | 100 | | |
| | *Maireana appressa* | | | | | | | | | | | | | 11 | | 33 | | |
| | *Maireana brevifolia* | | | | 5 | | | | | 20 | | 25 | | | | | | |
| | *Maireana coronata* | | | | | | | | | | | | 10 | | | | | |
| | *Maireana lobiflora* | | | | | | | | | | | | 10 | | | | | |
| | *Maireana pyramidata* | 67 | 100 | | 5 | 100 | | | | 60 | 33 | 75 | 100 | | | 33 | | 17 |
| | *Maireana* spp. | | | | 10 | | | | | | | | 10 | 6 | | | | 17 |
| | *Osteocarpum acropterum* | | 33 | | 5 | | | | 100 | | 33 | 25 | 20 | 6 | | 67 | | |
| | *Rhagodia spinescens* | | 33 | | 5 | 22 | | | | | | | 20 | | | | | |
| | *Salsola kali* var. *kali* | 33 | | | 10 | 56 | | 100 | 100 | 20 | | | 20 | 11 | | | | 17 |
| | *Salsola kali* var. *strobilifera* | | | | | | | | | | | | | 6 | | | | |
| | *Sclerochlamys brachyptera* | | | | 5 | | | | | | 33 | 25 | 10 | | | 67 | | 33 |
| | *Sclerochlamys* spp. | | | | | | | | | | | | 10 | | | | | |

| | Vegetation communities | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxon, family and name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
| **Number of quadrats** | **3** | **3** | **7** | **21** | **9** | **1** | **1** | **1** | **5** | **3** | **4** | **10** | **18** | **5** | **3** | **2** | **6** |
| *Sclerolaena bicornis* | 33 | 33 | | 19 | | | | 100 | 60 | | 50 | 10 | 11 | 20 | | | |
| *Sclerolaena brachyptera* | | | | | | | | | | | | 10 | | | | | |
| *Sclerolaena convexula* | | | | 14 | | | | | | | | | 11 | | 33 | | |
| *Sclerolaena decurrens* | | | | | | | | | | | 25 | 10 | | | | | 17 |
| *Sclerolaena diacantha* | 33 | 33 | | | 11 | | | | 40 | | 75 | 20 | | 20 | | | 17 |
| *Sclerolaena divaricata* | | 33 | | | | | | | | | | 10 | 6 | | | | |
| *Sclerolaena intricata* | 33 | 67 | 29 | 52 | 56 | | | 100 | 20 | | 50 | 20 | 11 | 40 | 33 | | 17 |
| *Sclerolaena lanicuspis* | 33 | | | | 44 | | | | | | | 20 | | | | | |
| *Sclerolaena muricata* | | | 14 | 29 | | | | | | | | | 50 | 20 | 67 | | 17 |
| *Sclerolaena obliquicuspis* | | | 14 | 14 | 44 | | | | | 33 | | 50 | | | | | |
| *Sclerolaena parallelicuspis* | | | | | | | | | | | | 10 | | | | | |
| *Sclerolaena patenticuspis* | | | | 5 | 11 | | | | | 33 | | 10 | | | | | |
| *Sclerolaena* spp. | | | | | | | | | | | | | 6 | | 67 | | |
| *Sclerolaena stelligera* | | | | 19 | | | | | 20 | | | | 11 | 20 | | | |
| *Sclerolaena tricuspis* | | 33 | | | 33 | | | | 20 | | | 20 | 6 | | 33 | | 17 |
| **Convolvulaceae** | | | | | | | | | | | | | | | | | |
| *Convolvulus clementii* | | | | | | | | | | | | | | | | | 17 |
| *Convolvulus remotus* | | | | | | | | | | | | | | | | | 17 |
| *Convolvulus* spp. | 33 | 67 | 14 | 10 | 33 | 100 | | 100 | 40 | 33 | 50 | 40 | 6 | | 33 | | 17 |
| **Crassulaceae** | | | | | | | | | | | | | | | | | |
| *Crassula colorata* | | | | | | | 100 | | | | | | | | | | |
| *Crassula* spp. | | 33 | | 10 | 22 | | | | | | | | | 20 | | | |
| **Cucurbitaceae** | | | | | | | | | | | | | | | | | |
| * *Cucumis myriocarpus* | | | | | | | | | | | | | | | 33 | | |
| **Euphorbiaceae** | | | | | | | | | | | | | | | | | |
| *Chamaesyce drummondii* | | 33 | 43 | | | | | | | 33 | | | | | | | |
| *Euphorbia* spp. | 33 | | | | | | | | 20 | | | | | | | | |
| *Sauropus trachyspermus* | | | | | | | 100 | | 20 | | | | | | | | |
| **Fabaceae** | | | | | | | | | | | | | | | | | |
| *Cullen cinereum* | | | | | | | | | 20 | | | | | | | | |
| *Glycine* spp. | | | | 5 | | | | | | | | | | | | | |
| *Lotus cruentus* | | | | 10 | | | | | | | | 20 | 11 | | | | |
| * *Medicago laciniata* | 33 | 67 | | 5 | | | | | 20 | 33 | | 40 | 6 | | | | |
| * *Medicago minima* | | 33 | | 5 | | | | | | 33 | 50 | 40 | 22 | 20 | 33 | 50 | 17 |
| * *Medicago polymorpha* | | | | | | | | | | | | | | | 33 | 50 | |
| * *Medicago* spp. | | | | | | | | | | | | | | 20 | | | |
| *Psoralea eriantha* var. *eriantha* | | | | | | | | | | | 25 | | | | | | |
| *Psoralea* spp. | 33 | | | | | | | | | | 25 | | | | | | |
| *Swainsona greyana* | | | 43 | | | | | | | | | | | | | | |
| *Swainsona phacoides* | | | | | | | | | 20 | | 50 | | 11 | | 33 | | |
| **Gentianaceae** | | | | | | | | | | | | | | | | | |
| * *Centaurium spicatum* | | | | 5 | | | | | 20 | | | 10 | 6 | | 67 | | |
| * *Centaurium* spp. | | | | | | | | | | | | | | 20 | 33 | | |
| * *Centaurium tenuiflorum* | | | | | 11 | | | | | | | | | 20 | 33 | | |
| **Geraniaceae** | | | | | | | | | | | | | | | | | |
| * *Erodium cicutarium* | | | | | 11 | | | | | | | 10 | | | 33 | 50 | |
| *Erodium crinitum* | | | | | | 100 | | | 20 | | | 10 | 11 | | | | |
| * *Erodium malacoides* | | | | | | | | | 20 | | | | | | | | |
| **Goodeniaceae** | | | | | | | | | | | | | | | | | |
| *Goodenia glauca* | | | | | | | | | | | | | 6 | | | | |
| *Goodenia gracilis* | | | | | | | | | | | 25 | 10 | | | | | |
| *Goodenia pinnatifida* | 33 | | | 5 | | | | | 20 | 33 | 50 | | | | | | 17 |
| *Goodenia* spp. | | 33 | | 5 | 11 | 100 | | 100 | 40 | 33 | 25 | | 6 | 20 | | | 33 |
| **Haloragaceae** | | | | | | | | | | | | | | | | | |
| *Haloragis aspera* | | | 14 | | | | | | 20 | | | | 11 | 20 | | | |
| *Haloragis* spp. | | | | | | | | | | | | | 6 | | | | |
| *Myriophyllum verrucosum* | | | | | | | | | | | | | | | 67 | | 33 |
| **Lamiaceae** | | | | | | | | | | | | | | | | | |
| * *Marrubium vulgare* | | | | 5 | | | | | | | | | | | | | |
| *Mentha australis* | | | 14 | 5 | | | | | | | | | | | | | |
| * *Salvia verbenaca* | | | | | | | | | | | | 10 | | | 67 | | |
| *Teucrium racemosum* | | | 29 | 29 | | | | 100 | 20 | 33 | 50 | 30 | 11 | 20 | 33 | | |
| **Loranthaceae** | | | | | | | | | | | | | | | | | |
| *Amyema lucasii* | | | | | 56 | | | | | | | | | | | | |
| *Amyema miraculosum* subsp. *boormanii* | | | | | | | | | | | | | 6 | | | | |
| *Amyema preissii* | | | | | | 100 | | | | | | | | | | | |
| *Amyema quandang* var. *quandang* | | | | | | 100 | | | | | | | | | | | |
| **Malvaceae** | | | | | | | | | | | | | | | | | |

| | **Vegetation communities** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxon, family and name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
| **Number of quadrats** | **3** | **3** | **7** | **21** | **9** | **1** | **1** | **1** | **5** | **3** | **4** | **10** | **18** | **5** | **3** | **2** | **6** |
| *Abutilon fraseri* | | | | | 11 | | | | | | | | | | | | |
| *Abutilon leucopetalum* | | | | | | 100 | | | | | | | | | | | |
| *Abutilon otocarpum* | | | | | | | | | 20 | | | | | | | | |
| *Malva australiana* | | | | 24 | | | | | 20 | | | | 22 | 20 | 100 | | |
| * *Malva parviflora* | | | | | | | | | | | | | 6 | 20 | | | |
| *Malvastrum americanum* | | | | | | | | | | | | 10 | | | | | |
| *Sida corrugata* | | | | | 11 | | | | | | | 10 | | | | | |
| *Sida intricata* | 33 | | | 5 | 11 | 100 | | 100 | 60 | | 25 | 30 | 6 | | | | |
| *Sida* spp. | | 33 | 14 | 5 | | | | 100 | | | 25 | 10 | | 20 | | | |
| **Mimosaceae** | | | | | | | | | | | | | | | | | |
| *Acacia aneura* | | | | | | 100 | | | | | | | | | | | |
| *Acacia ligulata* | | | | | | | 100 | | | | | | | | | | |
| *Acacia oswaldii* | | 33 | | | | 100 | | | | | | | | | | | |
| *Acacia stenophylla* | | | 43 | 10 | | | | | | | | | 6 | | | | |
| *Acacia victoriae* | 33 | | | | | | | | 100 | | 50 | | | | | | 17 |
| **Myoporaceae** | | | | | | | | | | | | | | | | | |
| *Eremophila bignoniiflora* | | | 14 | | | | | | | | | | | | | | |
| *Eremophila duttonii* | | | | | | | | | | | | | 6 | | | | |
| *Eremophila* spp. | | | | 5 | 11 | | | | | | | | | | | | |
| *Eremophila sturtii* | 33 | 33 | | | 33 | 100 | | | | | 25 | | | | | | |
| *Myoporum montanum* | | | | 5 | | | | | | | | | | | | | |
| *Myoporum platycarpum* | | | | 5 | | | | | | | | | | | | | |
| **Myrtaceae** | | | | | | | | | | | | | | | | | |
| *Eucalyptus camaldulensis* | | | 86 | | | | | | | | | | | | | | |
| *Eucalyptus coolabah* subsp. *coolabah* | | | 29 | 76 | | | | | | | | | | | | | |
| *Eucalyptus largiflorens* | | | | 38 | | | | | | | | | 6 | | | | |
| **Oxalidaceae** | | | | | | | | | | | | | | | | | |
| *Oxalis corniculata* | | | 14 | | | | | | | | | | | | | | |
| **Plantaginaceae** | | | | | | | | | | | | | | | | | |
| *Plantago cunninghamii* | 33 | | | 5 | | 100 | | | 20 | 33 | | 10 | 17 | | | 50 | |
| *Plantago drummondii* | | 67 | 14 | 29 | | | | 100 | 60 | | 75 | 30 | 28 | 60 | 67 | | 17 |
| *Plantago turrifera* | 67 | 33 | | 29 | 11 | | | | 60 | 33 | 25 | 50 | 11 | | | | 17 |
| **Polygonaceae** | | | | | | | | | | | | | | | | | |
| * *Acetosa vesicaria* | 33 | | | | | | | | | | | | | | | | |
| * *Emex australis* | | | | | | | | | | | 25 | | | | | | |
| *Muehlenbeckia florulenta* | | | 86 | 57 | | | | | | 33 | | | 94 | | | | |
| *Rumex brownii* | | | 29 | | | | | | | | | | | | | | |
| * *Rumex crispus* | | | | | | | | | | | | | | 20 | | | |
| *Rumex crystallinus* | | | | | | | | | | | | | | 40 | | | 17 |
| *Rumex* spp. | | | 43 | | | | | | | | | | | | | | |
| **Portulacaceae** | | | | | | | | | | | | | | | | | |
| *Calandrinia eremaea* | | 33 | | | | 100 | | | | | | | | 20 | | | |
| *Portulaca oleracea* | | | | 5 | | | | | | | | | | | | | |
| **Proteaceae** | | | | | | | | | | | | | | | | | |
| *Hakea leucoptera* | | | | | | | | 100 | | | 25 | | | | | | |
| **Ranunculaceae** | | | | | | | | | | | | | | | | | |
| *Myosurus minimus* var. *australis* | | | | | | | | | | | | | | 20 | | | |
| *Ranunculus pumilio* | | | | | | | | | | | | | | | 33 | | 17 |
| **Rubiaceae** | | | | | | | | | | | | | | | | | |
| *Asperula gemella* | | | 14 | | | | | | | | | | | | | | |
| *Psydrax oleifolium* | | | | | 11 | | | | | | | | | | | | |
| **Rutaceae** | | | | | | | | | | | | | | | | | |
| *Eriostemon linearis* | | | | | | | | | | | | | | | | 50 | |
| *Flindersia maculosa* | 33 | | | | 100 | | | | | | | | | | | | |
| **Sapindaceae** | | | | | | | | | | | | | | | | | |
| *Alectryon oleifolius subsp. canescens* | | 33 | | | 11 | | | | | | | | | | | | |
| *Atalaya hemiglauca* | 100 | | | | | | | | | | | | | | | | |
| *Dodonaea viscosa subsp. angustifolia* | 33 | | | | | 100 | | 100 | | | 50 | | | | | | |
| *Dodonaea viscosa subsp. angustissima* | | | | | | | | | | | 25 | | | | | | |
| **Scrophulariaceae** | | | | | | | | | | | | | | | | | |
| *Morgania floribunda* | | | | 5 | | | | | | | | | | | | | 17 |
| *Stemodia florulenta* | | | | 5 | | | | | 20 | | | | 6 | | 67 | | |
| **Solanaceae** | | | | | | | | | | | | | | | | | |
| *Lycium australe* | | | | | 11 | | | | | | | | | | | | |
| * *Nicotiana glauca* | | | | | | | | | | | | | | | 33 | | |
| *Nicotiana spp.* | | | 14 | | | | | | | | | | | | | | |

| | Vegetation communities | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxon, family and name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** |
| **Number of quadrats** | **3** | **3** | **7** | **21** | **9** | **1** | **1** | **1** | **5** | **3** | **4** | **10** | **18** | **5** | **3** | **2** | **6** |
| *Solanum esuriale* | 33 | | | | | 100 | | | 20 | | 25 | 10 | | | | | |
| * *Solanum nigrum* | | | 29 | | | | 100 | | | | | | | | | | |
| *Solanum* spp. | | | | 5 | | | | | | | | 20 | | | 33 | | 17 |
| **Thymelaeaceae** | | | | | | | | | | | | | | | | | |
| *Pimelea trichostachya* | | | | | 11 | | | | 20 | | 25 | 40 | | | | | |
| **Verbenaceae** | | | | | | | | | | | | | | | | | |
| * *Verbena supina* | | | | | | | | | | | | | 11 | | 33 | | |
| **Zygophyllaceae** | | | | | | | | | | | | | | | | | |
| *Zygophyllum ammophilum* | | | | | 11 | | | | | | | | | | | | |
| *Zygophyllum apiculatum* | 33 | | | | 11 | | | | | | | | | | | | |
| *Zygophyllum eremaeum* | | | | 5 | 11 | | | | | | | | | | | | |
| *Zygophyllum spp.* | | 33 | | 10 | 11 | | | | | | | | | | | | |

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# The peat-forming spring wetlands of the Strathbogie plateau – floristics and environmental relationships

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**Abstract*:*** Spring wetlands on the Strathbogie plateau were mapped using recent aerial photography to estimate their current and former extent. The floristic composition and relationships of the vegetation with topographic, environmental and land use variables were interpreted from an analysis of quadrat data. Wetland condition, threats to their persistence and future management requirements were also identified. More than half of the original wetland vegetation in the study area appears to have been lost, probably as a result of clearing for agriculture. Nine floristic assemblages, identified using agglomerative hierarchical clustering, were identified on acidic to mildly alkaline peat in five different hydrogeomorphic settings. One of these assemblages (Low Open Sedgeland) was uniquely confined to spring-fed mounds, not previously described in Victoria. A key to identification of these groups was developed. Floristic composition was correlated with climate and site disturbance but charcoal throughout sediment cores suggested that historical disturbance regimes included fire. Forested sites at higher elevations where grazing pressure appears to have been less intense were the least disturbed sites. Approximately 60% of the wetlands surveyed were assessed as showing signs of soil moisture loss but there was no evidence that water extraction via dams and known bores was a significant driver of current vegetation composition. Threats requiring management were related to habitat destruction and degradation, dysfunction of physical and biological processes, and changes to disturbance regimes. Establishment of native vegetation buffers and biomass management are likely to be of benefit for future management of spring wetland vegetation.

Key words: spring wetlands, disturbance, grazing, peat, management.

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## Introduction

Wetlands are a threatened vegetation type worldwide as a result of human impact (Mitsch & Gosselink 2007). Ecosystems which are entirely dependent on groundwater represent less than 1% of the land mass of the Australian continent (Hatton & Evans 1998) and include well known wetlands such as the mound springs of the Great Artesian Basin, the wetlands of the Swan Coastal Plain, karstic ecosystems and riparian red gum stands associated with inland groundwater ecosystems (Hatton & Evans 1998).

Wetlands provide a range of ecosystem services related to catchment hydrology and support distinct plant communities restricted to inundated or seasonally inundated parts of the landscape by virtue of their adaptation to waterlogging (Keddy 2010). In agricultural landscapes, year round water availability has historically made spring wetlands vulnerable to land use pressures (Keddy 2010). Spring wetlands may also be at risk from extractive activities that deplete groundwater reserves because of their value as a year round and permanent water supply.

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Classification of wetlands at landscape scale is typically linked to their role as functional units, based on hydrogeomorphic classes (Robertson & Fitzsimons 2004, Mitsch & Gosselink 2007) or hydrological setting (Ramsar Convention Bureau 1991). At the regional or management scale, these classes may be subdivided into ecological units based on the floristic and structural attributes of the vegetation (Fensham *et al.* 2004*a*).

In Victoria, wetlands have been mapped and classified as 127 different Ecological Vegetation Classes (EVCs), descriptive units encompassing a range of environmental variation from sea level to alpine regions including freshwater and saline systems (Department of Sustainability & Environment 2012). The primary intention of EVC mapping and classification is to provide an inventory of vegetation types for various planning and land management activities (Roberston & Fitzsimons 2004) and condition assessments (DSE 2012).

The delineation of Victorian spring wetland vegetation communities has been difficult, partly because examples are severely altered from their original condition and are patchily distributed across the landscape, and partly owing to a lack of systematic surveys. For example, the current EVC description for ‘Spring-soak Woodland’ is derived from only a handful of remnants in north-eastern Victoria, almost all of which consist of only a subset of species with fidelity to the EVC. Within any single EVC, a range of vegetation communities also occurs, according to local site environmental variation and/or disturbance history.

The relationships between wetland plant communities and environmental variables remain generally unquantified in south-eastern Australian classifications (Roberston & Fitzsimons 2004). To date, the most comprehensive ecological studies of spring wetland vegetation have focused on mound springs associated with the Great Artesian Basin (Fensham & Fairfax 2003, Fensham & Price 2004, Fensham *et al.* 2004*a*, Fensham *et al.* 2004*b*). Other studies have investigated the influence of water regime on vegetation patterns and ecosystem function with a view to formulating management directions at broader scales, although field-based vegetation community level studies are still generally lacking (Eamus *et al.* 2006, Raulings *et al.* 2010).

Spring wetlands are rare in the Victorian landscape, particularly at lower elevations. These wetlands are subject to a range of threats, the majority of which derive from land uses incompatible with their preservation and it is likely that most have been destroyed, or severely altered from their original condition since European settlement. To date, no systematic surveys have been conducted in spring wetlands or related groundwater dependent vegetation in Victoria, other than in alpine and subalpine areas (Ashton & Hargreaves 1983, Wahren *et al.* 1999, Whinam *et al.* 2003, Coates *et al.* 2012). Consequently, their floristic composition and contribution to biodiversity are poorly understood and any prescriptions for management are hampered by a current lack of knowledge of floristics, condition, threats and environmental relationships.

The wetlands surveyed in this study support remnant vegetation communities that have developed on and around groundwater-fed springs on the Strathbogie plateau in central Victoria and represent a unique ecosystem in the State. To contribute to an understanding of their management requirements applicable at the site scale, the aims of the current study were to, 1) describe the floristic variation, structure and environmental correlates of remnant spring wetlands; 2) determine their current and former extent, and 3) determine their current condition and threats to their persistence.

## Methods

### *Study area*

The study area covers 2 568 km$^2$ (Phillips *et al.* 2002) and is roughly 150 km northeast of Melbourne (37º 00’ 30” S, 145º 27’ 50” E; Figure 1). The plateau is part of a batholith consisting of two coarse-grained granite plutons, formed from a Middle to Upper Devonian intrusion (370–390 m.y.), with a mildly dissected surface of rolling to hilly tableland at about 320–700 m asl. The plateau straddles the Broken River and Goulburn River catchments and exerts major control over river patterns and groundwater flow (Phillips *et al.* 2002).

The hydrogeology of the Strathbogie Plateau has not been studied in detail but is thought to conform to a conceptual model for fractured rock aquifers, described by Stewardson *et al.* (2009). In their model, fluvial erosion through the weathered batholith surface has established valley floors in the erosion-resistant basement rock. Drainage is to the west-southwest, following the orientation of the basement surface, also the dominant surface flow direction of both plutons. Stewardson *et al.* (2009) proposed that the hills surrounding these valleys consist mostly of isolated fractured rock aquifers. Groundwater is discharged from these aquifers via springs located where river valleys intersect with basement rock. Owing to the orientation of the basement surface, springs on the west-southwest side of hills are likely to have a more persistent flow. More intermittent flows can be expected where groundwater discharge occurs at the intersection of hill surfaces and the aquifer water table. Springs are also most likely to occur along valley margins rather than within drainage lines. Palustrine-type wetlands (Ramsar Convention Bureau 1991) have developed around spring outlets at higher elevations on the plateau.

The nearest weather station is at Strathbogie, roughly 40 km to the north of the study area (36° 51’ 50” S, 145° 44’ 51” E). January and February are the hottest and driest months, with a mean maximum temperature of 27.3°C, mean minimum of 11.6°C and mean monthly precipitation of 46 mm (Bureau of Meteorology, online). The elevation of the plateau mediates the summer heat of the surrounding plains. Prevailing winds are variable, tending southerly to northerly and reaching the highest speeds (11–13 km/hr on average) between early spring and late summer, weakening over autumn and winter

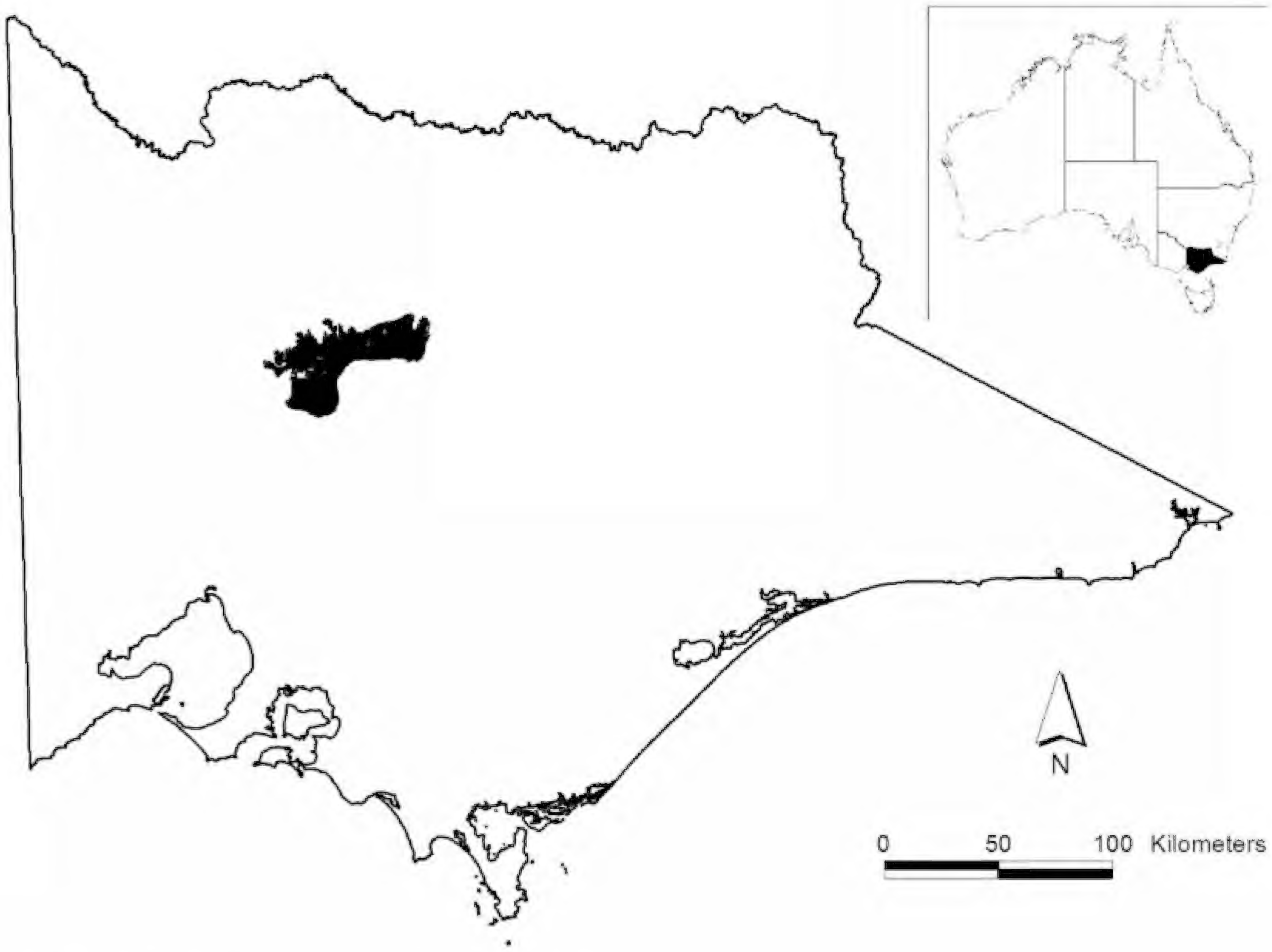

**Fig. 1.** Location of the study, shown as the area of Strathbogie granite.

to about 9 km/hr. Winters are relatively cold and wet. The average maximum temperature in July is 10.1°C, the average minimum is 1.6°C, and mean precipitation is 123 mm. Rain (>1mm) falls for 91 days per year on average and snow may fall occasionally (Bureau of Meteorology, online). Rainfall and temperatures are likely to vary over the plateau with altitudinal and topographic variation.

The pre-European vegetation of the study area generally consisted of "lightly forested grassland, dotted with large granite outcrops and numerous springs and creeks" (McCall 1982 cited in Gubbins 2010). However, depressions where trees were cleared are still clearly visible in paddocks and imply that the vegetation may have been relatively dense on lower slopes. Much of the native vegetation was cleared in the mid to late 19th century and replaced with herbaceous pasture species.

The major current land use is grazing by domestic stock, predominantly cattle but also sheep (Carr *et al.* 2006). The consequences of disturbance by stock include soil compaction, localised turbidity, eutrophication via faeces and urine, pugging of soils and destruction of peat, and ponding of water in micro-topographic relief features resulting in increased water loss by evaporation (Carr *et al.* 2006). Water extraction by bores and construction of farm dams above or below springs are common on freehold land in the study area (Carr *et al.* 2006). Other disturbance includes draining of wetlands via channels and planting of high water-use trees, notably blue gum (*Eucalyptus globulus*) plantations adjacent to or near wetlands. The effect of plantations on watertables is unknown. Other major impacts to wetland condition are weed invasion by pasture species, inadvertent off-target damage to vegetation by poor herbicide use, and broadacre application of fertilisers (Carr *et al* 2006).

Bushfires were first recorded in 1851 in the region (White *et al.* 1990), although the precise area or whether the Strathbogie plateau burnt, is not clear. Fires occurred in the first half of the century in 1904, 1908, 1922, 1939 but none have been recorded since 1983 (Gubbins 2010). Fires are likely to have been extensively used to clear land around the time of settlement between 1841 and the early 20th century (Mackrell 1977, Mc Call 1982, both cited in Gubbins 2010), although clearing still occurred in the 1940s (J. Webb, "Kobyboyne" pers. comm.).

The study sites encompassed a range of peat-forming spring wetlands (mires). Peat was defined as organic sediments formed on permanently saturated organic soils and exceeding 20% dry weight (Whinam & Hope 2005, Hope *et al.* 2011). More specifically, the wetlands consist of fen and swamp forest (or wooded fen), as adapted for usage within Australasia (Whinam & Hope 2005, Hope *et al.* 2011). The term 'fen' is used to describe vegetation dominated by peat-forming graminoid species, while 'swamp forest' describes vegetation dominated by tall shrubs and trees (Whinam & Hope 2005). Sites allied with baseflow rivers and streams, flood plains or alluvial environments associated with flowing water were excluded.

### *Mapping*

Wetlands in the study area were mapped in GIS (Arcview 3.3) using geo-rectified aerial photography (50 cm pixel resolution) collected in 2007. Mapping was also informed by field notes compiled from inspection of total wetland extent. These notes described the full range of vegetation communities and threats (see below). This allowed us to identify various vegetation types in the aerial images. The average size of the wetlands assessed was approximately 4 ha.

Additional data were extracted from 311 grid locations from a previous survey (Carr *et al*. 2006) and mapped if detectable in the imagery. In the absence of ground-truthing it was not possible to distinguish precise vegetation groups from aerial photographs. Therefore, all wetlands or sections thereof were mapped as one of four broad vegetation types: forest/woodland; shrubland; sedgeland/reedland, and 'remnant' (patches of *Juncus sarophorus*, *Carex* spp. and other non-woody vegetation associated with seepage areas in paddocks). The 'remnant' category was assumed to have once supported wetland vegetation and its total area was included to calculate the estimated (and conservative minimum) loss of wetland vegetation in the study area since European settlement. We made a number of assumptions to identify likely remnants, namely: the Strathbogies were largely forested at European settlement and paddocks are therefore an artefact of clearing, without the wetland vegetation that might once have existed there; peaty soils in paddocks once supported wetland vegetation communities all of which remains is a small number of rushes or sedges, mainly *Juncus sarophorus*; former areas of wetland are visible on aerial photography as darker areas most likely indicating wetter soils.

### *Vegetation survey*

Forty-one wetlands identified in a previous study (Carr *et al*. 2006) were selected according to the following criteria: a range of condition states; accessibility; distinguishable on colour aerial photographs; spanned the geographic and altitudinal ranges of the study area; likely to represent the range of floristic compositional variation and with a known management history.

To describe the floristic variation of the wetlands, percent cover (estimated visually) of all vascular plant species and *Sphagnum* spp. was recorded in quadrats (10m x 10 m) in each of the 41 wetlands in September to November 2008. Quadrats were located near to the point of groundwater discharge and where the vegetation was considered most intact. Plant nomenclature follows Walsh & Stajsic (2006); community structural typology follows Specht *et al*. (1974) and EVC typology follows Department of Sustainability & Environment (2012).

In each quadrat geographic position; quadrat position in the wetland (centre, middle, outer); elevation (metres ASL); slope aspect and angle (using a Suunto compass and clinometer); percent cover (estimated visually to the nearest 10%) and depth of standing water were recorded. Synthetic climate parameters for a range of rainfall and temperature variables were generated for each quadrat using the BIOCLIM module (Nix and Busby 1986) of the ANUCLIM package (Houlder *et al*. 2005).

A condition descriptor derived from the proportion of three variables was used as a surrogate for site condition in each quadrat [(% pugging + % tracks + % weed cover)/100]. The proportion of the ground covered by pugging and tracks was estimated visually. Weed cover (percent), weed species richness and native species richness were derived from the floristic survey. Other variables recorded were proportion of the wetland perimeter buffered by vegetation with >25% native species cover (estimated in the field and using GIS); overall wetland buffer width (estimated in the field and using GIS); distance and direction (upslope, downslope, across slope) to the nearest dam; distance to the nearest bore, and years fenced.

A sediment core (50 mm x 1 m gouge auger, Dormer Engineering) was taken in each quadrat to determine the depth of the peat layer and the depth to the impermeable layer. The presence of charcoal particles was recorded as an indication as to whether sites were likely to have been burnt at any time in the past. Three soil samples were collected at a depth of 15 cm in each quadrat and bulked for the following analyses: pH of the A horizon (TPS Digital pH meter calibrated with a buffer solution to pH 7, 1:1 ratio of soil to de-ionized distilled water, using 20 gm of soil : 20 ml of water); % moisture and % organic content of the A horizon (measured using loss on ignition, Dean 1974).

To determine the degree to which compositional variation might be associated with landform morphology, each quadrat was assigned to one of five hydrogeomorphic classes based on landform setting and hydrologic dynamics (Semeniuk & Semeniuk 1997). These classes were derived from slope angle and land surface shape and fell into two categories. Topogenous sites were those situated on more or less flat terrain below slopes or within basins, with no outlet, a single outlet or both inlets and outlets (Ryadin & Jeglum 2006). These sites appeared to receive water from springs situated throughout the drainage line and/or lateral slopes, as well as a significant amount from sub-surface flows and surface run-off. Soligenous sites were generally associated with slope-breaks, receiving groundwater at its point of expression above the surface, with only minor inflows from soil water drainage and surface runoff (Ryadin & Jeglum 2006).

Hydrogeomorphic classes were: 1, Vales: broad depressions flanked by hillslopes <$5^0$ (topogenous); 2, gullies: flanked by hillslopes >$5^0$ (topogenous); 3, slopes <$5^0$: flat or near flat, or with a distinct concave depression (soligenous); 4, slopes >$5^0$: sloping, or with a distinct concave depression (soligenous); and 5, mounds: convex formations associated with spring vents (soligenous).

### *Threats*

Threats, management issues and other site parameters that might influence wetland condition or function, or might require management in future were noted during field mapping. These included: land use; recent or planned changes to land use/management; physical threats; vegetation connectivity (as a measure of overall intactness and fragmentation); vegetation zonation (% of identifiable floristic assemblages intact, estimated visually in the field and from aerial photography); the proportion of wetland soils that were dry/damp and wet/waterlogged (estimated in quadrats and data combined for each wetland site) and any obvious qualitative or quantitative changes to the water regime (Department of Sustainability & Environment 2006). Dry soils clearly contained no or very little moisture and damp soils had limited or no ability to release excess water when a handful of soil was manually compressed; saturated or waterlogged soils were identified as having excess water present, which was freely released with or without light compression.

### *Analytical methods*

To identify vegetation groups, floristic data were analysed by hierarchical agglomerative clustering using average linkage (Oksanen 2011). Species that occurred in fewer than 10% of quadrats were excluded. Compositional dissimilarities were calculated using the Bray-Curtis co-efficient (Faith *et al.* 1987). Unique clusters were identified at the nine group level, considered sufficient to represent the range of vegetation communities observed in the field. A dendrogram was constructed to display group similarity and a dichotomous key was devised to assist with recognition of the vegetation groups in the field.

Differences in mean soil organic and moisture content were compared among hydrogeomorphic classes using a One-way Analysis of Variance. Quadrat variables according to floristic groups were compared using interval plots (Minitab 2010). Pearsons Product-Moment correlation co-efficient was used to test for significant relationships between organic and moisture content, pH, slope angle, precipitation, altitude. Results were considered significant if $P < 0.05$.

The Bray Curtis dissimilarity matrix of floristic data was then ordinated using non-metric multidimensional scaling (NMDS) from several random starts until a solution with the smallest acceptable stress was reached. To determine an appropriate dimensionality, the solution was chosen that provided the most reduction in stress (McCune & Grace 2002). Quadrats were then plotted in the ordination space and labelled according to cluster group membership. To determine the degree to which compositional variation could be explained by wetland management and/or environmental attributes, directional vectors for the variables measured during the quadrat survey were fitted through the ordination space (Kantvilas and Minchin 1989). Only those variables which satisfied the assumption of linearity and normality were used, tested by fitting surfaces of each of the variables to the ordination and using the Johnson transformation (Minitab 2010).

Data manipulation, statistical analyses and graphics were conducted using Program R Version 2.14.1 (R Development Core Team 2011) with packages MASS (Venables & Ripley 2002) and Vegan version 2.1–14 (Oksanen *et al.* 2012) and Minitab® 16.1.0 Statistical Software (Minitab Inc. 2010).

Threats were compiled and allocated to ecological risk categories (Auld & Keith 2008) to give general context to address potential management issues.

## Results

### *Mapping*

A total area of 1646 hectares of wetlands vegetation and remnant wetland vegetation was mapped from aerial photos, representing 0.65% of the total study area. Four broad structural vegetation types were recognised at a landscape scale, representing a gradient of canopy cover: (i) treeless vegetation of fens dominated by rushes, reeds or sedges; (ii) shrublands; (iii) swamp forest and woodland and (iv) remnants dominated by rushes and grasses.

'Remnant' accounted for most (58%; Table 1) of all mapped wetland vegetation and forest/woodland the least (2.5%; Table 1). Roughly one quarter of the vegetation mapped was dominated by sedges and reeds and roughly 15% was shrub-dominated (Table 1).

The full extent of wetlands could not be accurately assessed from aerial imagery for two reasons. Firstly, wetlands were difficult to detect when they were under tree canopy, and the limited areas mapped within the forest or woodland category were mostly those that had been detected during the field surveys. Therefore, the total area of this wetland type is likely to be substantially underestimated. Secondly, in many parts of the study area, particularly in the south, wetland vegetation that would be expected to occur around the numerous dams and drainage lines was not discernible in aerial photos.

**Table 1. Broad wetland vegetation types mapped within the study area (1,646 ha).**

| Vegetation type | Number of polygons mapped | Mapped area (hectares) | % of mapped wetlands |
|---|---|---|---|
| Forest/woodland | 65 | 41.8 | 2.5 |
| Shrub-dominated | 303 | 247.7 | 15.1 |
| Sedge/reed-dominated | 572 | 398.2 | 24.2 |
| Remnant | 805 | 958.6 | 58.2 |

## Vegetation survey

Two hundred and three species were recorded from 68 quadrats in 47 wetlands. Quadrats were fairly uniformly spread over a range of altitudes (300–620 m). Fewer quadrats were sampled at lower altitudes (20% were below 500 m) than at higher altitudes, indicating that these sites were relatively rare. The introduced pasture species *Holcus lanatus*, *Anthoxanthum odoratum* and *Lotus corniculatus* were ubiquitous components of ground layers, and were recorded in more than 70% of quadrats.

The majority of quadrats (41) consisted of soligenous systems associated with a break in steep slopes ($>5^0$) or gentle slopes ($<5^0$) where bedrock or an impermeable layer was at, or close to the surface. Just over half of these sites were located on broadly planar land surfaces, with the remainder in broadly concave depressions. Runoff from these sites sometimes converged into distinct drainage lines.

Six soligenous sites were recorded on ‘mounds’ located on steep or gently sloping hillsides. Spring-fed mounds appear to be an undescribed landform element in Victoria. They were distinctly convex and usually about 2–4 m in diameter. Mounds had a clearly defined vent and are likely to have been formed by localised upwelling of groundwater, resulting in unstable, raised areas of saturated peat. Related, larger landform features have been described elsewhere as mound springs, associated with the Great Artesian Basin (Fensham *et al*. 2004*a*, *b*), tumulus (organic mound) springs in Western Australia (Blyth & English 1996), and spring-fen mounds or groundwater mounds in Europe, North America and Japan (Ryadin & Jeglum 2006, Tomita 2008). Topogenous sites were situated in vales (17) and in gullies (7). These sites received water from inflow and from springs situated along banks, or via mounds situated within the main drainage lines.

Cores were taken from 47 quadrats but high water content prevented successful extraction from the remainder of quadrats, particularly in mounds. The stratigraphy of sites was reasonably consistent throughout the study area. All sites, with few exceptions, consisted of an A horizon between 3 and 80 cm deep comprising reddish-brown peat or (rarely) organic loam, overlying grey to yellow-grey medium clays generally from about 85–100 cm and an impermeable layer situated above weathering bedrock. Mounds tended to contain unconsolidated gravels or fine sands in the region above the impermeable layer, at approximately 2 m depth. An increase in moisture was detected below the impermeable layer at two sites, suggesting the presence of perched water tables.

Charcoal was recorded at the boundary between peat and clay layers and throughout the deeper clay layers but less commonly in the upper peat layer. Soil A horizons were acidic (pH 5) to mildly alkaline (pH 7.9). Most sites were peat (>70% of sites), with the remainder organic loam (i.e. having <20% organic content).

Moisture content was highly variable among quadrats, ranging from only 20% at the driest site to 95% at saturated sites. The organic content of the A horizon varied from 6% to 80% among quadrats. The highest accumulation of organic content was on mounds, although the sample size was small (6 sites). However, there was no statistically

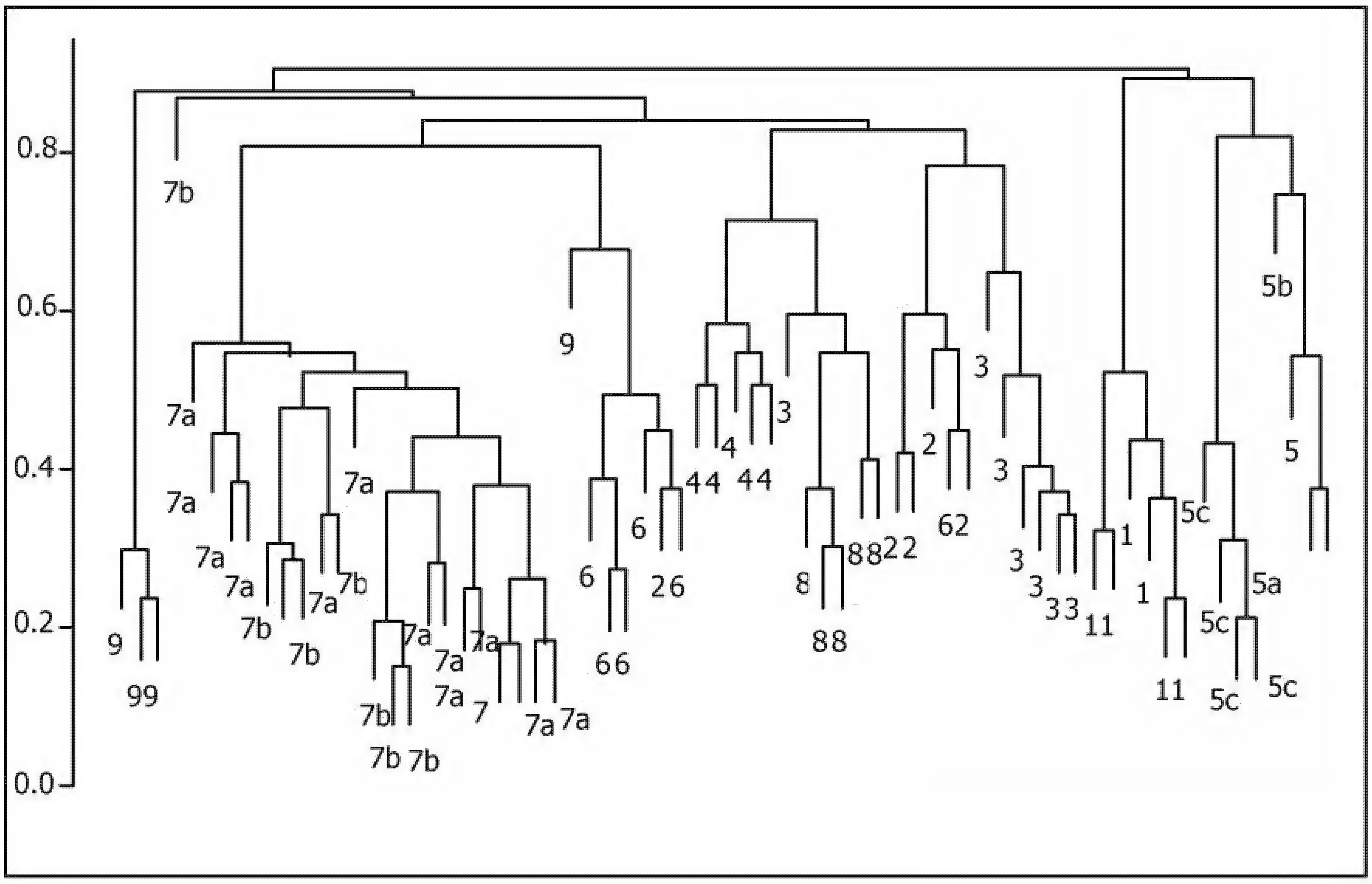

**Fig. 2.** Dendrogram produced from agglomerative hierarchical clustering of floristic data. Clusters are labelled by floristic group membership. The lengths of the vertical lines represent Bray-Cutis dissimilarity.

significant difference in mean moisture content or organic content of the A horizon among hydrogeomorphic classess ($P < 0.05$). There was a strong positive relationship between organic content and moisture content ($r = 0.84$, $P < 0.001$), suggesting that peat was better developed in wetlands that showed less signs of drying out, at least toward the wetland centre where quadrats were typically sampled.

### *Vegetation groups*

Nine floristic assemblages were derived from the floristic survey, although there was a degree of overlap in the composition of some of the vegetation groups (Figure 2). There were some significant differences between various vegetation groups for altitude, soil moisture, organic content, rainfall, temperature, native species richness, weed species richness, weed cover, buffer width and length and years fenced, distance to the nearest bore, percent pugging and disturbance (Table 2). However, no group was consistently different from any other and there was a large amount of variation in the data (Table 2).

### Group 1. *Phragmites australis* Reedland

Dominated by tall dense to mid-dense stands (> 50% cover) of *Phragmites australis* with a sparse to moderately dense (5–60% cover) mid-stratum of sedges such as *Carex appressa, Carex fascicularis* or *Carex gaudichaudiana* (Appendix 1). The ground layer is predominantly introduced species, particularly *Holcus lanatus* and *Lotus corniculatus*. *Eucalyptus camphora* subsp. *humeana*, *Leptospermum lanigerum* and *Dicksonia antarctica* are recorded as occasional emergents. Mean native species richness (7) in this group is half or less than that recorded in other groups, significantly so in some cases ($P < 0.05$; Table 2).

Distributed across the study area at a range of altitudes (380–590 m) but mainly at sites with relatively low mean annual rainfall (829 mm), this community is confined to saturated, topogenous sites with standing water in the central zone of vales or gullies (mean soil moisture = 77%).

Referable to Tall Marsh (EVC# 821).

**Table 2. Mean values (±SD) of environmental variables recorded for each vegetation group.**
Means that do not share a letter are significantly different.

| Group | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Peat depth (cm) | 14±4.8$^{A}$ | 4±1.4$^{A}$ | 26±27$^{A}$ | 28±18$^{A}$ | 20±11.3$^{A}$ | 36±17$^{A}$ | 21±13$^{A}$ | 18±25$^{A}$ | 14±3$^{A}$ |
| pH | 7.2±0.3$^{A}$ | 6.6±0.7$^{A}$ | 6.4±0.4$^{A}$ | 6.9±0.2$^{A}$ | 6.5±0.9$^{A}$ | 6.6±0.5$^{A}$ | 6.7±0.6$^{A}$ | 6.7±0.6$^{A}$ | 6.9±0.1$^{A}$ |
| % organic | 43±20$^{AB}$ | 28±23$^{AB}$ | 24±21$^{B}$ | 63±12$^{A}$ | 34±15$^{A}$ | 43±18$^{AB}$ | 52±21$^{AB}$ | 52±26$^{AB}$ | 38±28$^{AB}$ |
| % moisture | 77±15$^{AB}$ | 60±22$^{AB}$ | 53±22$^{AB}$ | 88±5$^{A}$ | 64±21$^{AB}$ | 75±23$^{AB}$ | 80±14$^{A}$ | 84±8$^{AB}$ | 73±10$^{AB}$ |
| Altitude (m) | 472±86$^{C}$ | 459±45$^{C}$ | 543±29$^{AB}$ | 382±103$^{C}$ | 582±33$^{A}$ | 545±32$^{AB}$ | 533±49$^{AB}$ | 507±94$^{AB}$ | 578±41$^{AB}$ |
| Mean annual precipitation (mm) | 829±78$^{AB}$ | 793±24$^{B}$ | 947±70$^{A}$ | 811±124$^{AB}$ | 845±96$^{AB}$ | 904±108$^{AB}$ | 902±68$^{AB}$ | 933±55$^{AB}$ | 844±46$^{AB}$ |
| Mean annual temperature ( C) | 12.1±0.5$^{A}$ | 12.1±0.2$^{AB}$ | 11.9±0.2$^{AB}$ | 12.3±0.7$^{A}$ | 12±0.5$^{AB}$ | 11.8±0.5$^{AB}$ | 11.6±0.2$^{B}$ | 11.9±0.3$^{AB}$ | 11.8±0.4$^{AB}$ |
| Native species richness | 7.3±3.9$^{C}$ | 9.2±4.9$^{BC}$ | 21.3±7.4$^{A}$ | 17.6±2.3$^{ABC}$ | 17.1±6.1$^{ABC}$ | 19.2±7.3$^{AB}$ | 15.3±6.5$^{ABC}$ | 15.8±4.6$^{ABC}$ | 22±6.4$^{AB}$ |
| Weed species richness | 5.5±2.4$^{B}$ | 6.8±1.5$^{AB}$ | 6.9±1.9$^{AB}$ | 10±2.1$^{A}$ | 7.4±2.1$^{AB}$ | 9±2.6$^{AB}$ | 5.7±2.2$^{B}$ | 7.2±2.8$^{AB}$ | 5.8±2.1$^{AB}$ |
| Weed cover (%) | 19±17.2$^{ABC}$ | 43±12$^{A}$ | 25±11.1$^{ABC}$ | 31±26.8$^{AB}$ | 7±6.1$^{C}$ | 19±11.5$^{ABC}$ | 12±11.9$^{BC}$ | 13±9.8$^{BC}$ | 3±2.5$^{BC}$ |
| Buffer width (m) | 26±47$^{AB}$ | 21±35$^{AB}$ | 34±32$^{AB}$ | 0$^{B}$ | 151±216$^{A}$ | 27±29$^{AB}$ | 30±42$^{B}$ | 0$^{B}$ | 61±28$^{AB}$ |
| Buffer length (m) | 17±27$^{AB}$ | 34±65$^{AB}$ | 34±34$^{AB}$ | 0$^{B}$ | 70±41$^{A}$ | 57±56$^{AB}$ | 23±28$^{B}$ | 0$^{B}$ | 58±30$^{AB}$ |
| Years fenced | 3.2±4.5$^{AB}$ | 1.2±2.2$^{B}$ | 3.1±3.8$^{AB}$ | 0.1±0.2$^{B}$ | 2.5±3.8$^{B}$ | 4.2±3.8$^{AB}$ | 2.6±3.5$^{B}$ | 0.5±0.5$^{B}$ | 11.3±12.5$^{A}$ |
| Distance to bore (m) | 3617±1710$^{AB}$ | 2304±1681$^{B}$ | 1477±851$^{B}$ | 6440±1831$^{A}$ | 3513±2262$^{B}$ | 920±550$^{B}$ | 2588±1422$^{B}$ | 3640±2251$^{AB}$ | 2795±1344$^{B}$ |
| Distance to dam upslope (m) | 0$^{A}$ | 12±27$^{A}$ | 0$^{A}$ | 40±89$^{A}$ | 15±25$^{A}$ | 0$^{A}$ | 27±49$^{A}$ | 142±275$^{A}$ | 20±40$^{A}$ |
| Distance to dam downslope (m) | 432±279$^{A}$ | 226±173$^{A}$ | 119±162$^{A}$ | 80±148$^{A}$ | 366±582$^{A}$ | 97±101$^{A}$ | 174±277$^{A}$ | 76±98$^{A}$ | 48±59$^{A}$ |
| Distance to dam across slope (m) | 0$^{A}$ | 0$^{A}$ | 23±41$^{A}$ | 44±67$^{A}$ | 9±25$^{A}$ | 13±33$^{A}$ | 54±162$^{A}$ | 0$^{A}$ | 10±20$^{A}$ |
| % pugging | 0.5±0.5$^{B}$ | 0.5±0.6$^{B}$ | 2±3.5$^{B}$ | 35±40$^{A}$ | 1±1.7$^{B}$ | 2±1.5$^{B}$ | 1±1.4$^{B}$ | 3±2$^{B}$ | 2±2.4$^{B}$ |
| % tracks | 1±2$^{A}$ | 3±2$^{A}$ | 2±1.9$^{A}$ | 6±13.3$^{A}$ | 8±7.7$^{A}$ | 4.8$^{A}$ | 5±4.6$^{A}$ | 0$^{A}$ | 8±4$^{A}$ |
| Disturbance | 0.2±0.2$^{ABC}$ | 0.5±0.1$^{AB}$ | 0.3±0.1B$^{C}$ | 0.7±0.4$^{A}$ | 0.2±0.1$^{C}$ | 0.3±0.1B$^{C}$ | 0.2±0.1$^{C}$ | 0.2±0.1$^{C}$ | 0.1±0.1$^{C}$ |

### Group 2. *Juncus sarophorus – Carex appressa* Sedgeland

This community is dominated by *Juncus sarophorus* and *Carex appressa* (30–70% combined cover) and a moderately dense to dense ground layer (30–80% cover) mainly consisting of introduced pasture species such as *Holcus lanatus*, *Anthoxanthum odoratum* and *Lotus corniculatus*. *Eucalyptus camphora*, *Acacia melanoxylon* and *Leptospermum lanigerum* are occasional emergents (Appendix 1).

*Juncus sarophorus – Carex appressa* Sedgeland is common on both topogenous vales across a range of elevations (390–500 m) at sites with relatively low mean annual rainfall (793 mm). It occurs on drier sites than group 1 (Table 2) and is commonly seen as remnant wetland vegetation in paddocks along shallow drainage lines and at the margins of wetlands.

Referable to Wet Verge Sedgeland (EVC# 932).

### Group 3. *Baeckea utilis* Shrubland

Dominated by moderately dense stands (> 40% cover) of *Baeckea utilis* to 4 m high and occasionally co-dominated by *Epacris brevifolia* or *Leptospermum continentale* (Appendix 1). The ground layer mainly consists of exotic grasses and herbs (*Holcus lanatus*, *Anthoxanthum odoratum*, *Lotus corniculatus*) but also with a high level of species richness (Table 2). Co-occurring native species include *Poa helmsii* and other monocot species (e.g. *Baumea rubiginosa*, *Arthropodium milleflorum*, *Luzula meridionalis*). Native herbs are less consistently represented but may include *Gonocarpus micranthus*, *Hydrocotyle* spp., *Drosera peltata*, *Craspedia paludosa* or *Euchiton involucratus*. *Eucalyptus camphora* may be an occasional emergent.

Confined to the northern Strathbogies at higher elevations (500–575 m), *Baeckea utilis* Shrubland tends to occur as isolated thickets in soligenous situations along breaks in gentle or steeper slopes on shallow soils, at the margins of *Eucalyptus camphora* open forest and as discontinuous patches in cleared paddocks. Soil moisture and organic content values were the lowest recorded during the survey (53% and 24% respectively; Table 2).

Referable to Perched Boggy Shrubland (EVC# 185).

### Group 4. *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland

This community occurs on wet sites dominated by *Leptospermum lanigerum* (10–30% cover) to 1.5 m

## Key to Groups

1. Trees absent or sparse (cover <5%), dominated by shrubs, reeds, rushes or sedges ........ 2
1. Trees present (cover >5%), or if absent or sparse not dominated by rushes, reeds or sedges (shrubs usually present) ........ 3

2. Shrubs (*Leptospermum* spp., *Baeckea utilis*) dominant ........ 8
2. Reeds, rushes or sedges dominant ........ 10

3. Swamp woodland with ground layer or understorey of shrubs or coral fern (>25%) ........ 4
3. Swamp woodland with ground layer of sedges and/or other ferns ........ 5

4. Swamp woodland with ground layer dominated by coral fern ........ GROUP 9
4. Swamp woodland with understorey dominated by shrubs ........ 8

5. Swamp woodland with ground layer of sedges, bracken and *Blechnum* ........ GROUP 5b
5. Swamp woodland with ground layer mainly of sedges (>25%) ........ 6

6. Open swamp forest with a ground layer dominated by *Gahnia* or *Carex* ........ 7
6. Swamp woodland with a ground layer dominated by *Baumea* ........ GROUP 7a

7. Open swamp forest with a ground layer dominated by *Gahnia sieberiana* ........ GROUP 5a
7. Open swamp forest with a ground layer dominated by *Carex appressa* ........ GROUP 5c

8. Understorey consisting of tall shrub thickets (2 m)9
8. Understorey consisting of low shrubs (< 2m) ........ GROUP 4

9. Open swamp forest or shrubland dominated by *Leptospermum lanigerum* ........ GROUP 6
9. Open swamp forest or shrubland dominated by *Baeckea utilis* ........ GROUP 3

10. Tall reedland (> 2m) ........ GROUP 1
10. Dominated by rushes or sedges ........ 11

11. Dominated by rushes (*Juncus*) ........ GROUP 2
11. Dominated by sedges ........ 12

12. Swamp woodland, ground layer dominated by *Baumea* ........ GROUP 7a
12. Sedgeland, swamp gum absent ........ 13

13. *Baumea* spp. >25% cover ........ 14
13. Small graminoids and forbs dominant (< 25% cover) ........ GROUP 8

14. *Gleichenia* and *Baumea* spp. co-dominant ........ GROUP 9
14. *Baumea* dominant ........ GROUP 7b

(occasionally taller) and *Baumea rubiginosa* with a high diversity of graminoid and herbaceous species in the ground layer (Appendix 1). These include *Holcus lanatus*, *Eleocharis gracilis*, *Juncus planifolius*, *Phragmites australis*, *Schoenus* spp., *Isolepis* spp., *Triglochin striata*, *Utricularia dichotoma* and *Hypericum japonicum*.

The community is found at significantly lower mean elevation (380 m, $P < 0.001$) than any other group except 1 and 2 (Table 2). It occurs in soligenous settings around spring outlets within vales as well as on gentle or steeper slopes to the south of the study area. Soils had high organic and moisture content (Table 2). Disturbance was also significantly higher than in any other group except 1 and 2 ($P < 0.001$; Table 2). The presence of remnant stands of *Leptospermum lanigerum* suggests that this community may eventually regenerate to Thicket Swamp Forest (see below) in the absence of stock disturbance.

Referable to Perched Boggy Shrubland (EVC# 185) and Swamp Scrub (EVC# 53).

### Group 5. *Acacia melanoxylon* Swamp Forest

This group contains three related swamp forest communities dominated by *Acacia melanoxylon* distributed over a soil moisture gradient and distinguished by understorey composition. Different disturbance histories are also likely to have determined the current floristic composition of the understoreys but sites also had low weed cover (Table 2). Quadrats were located on gently sloping terrain and within vales and gullies; however, low moisture content (Table 2) suggests that most sites appear to be drying out.

Referable to Fern Swamp (EVC# 721) and Swampy Woodland (EVC# 937).

### Group 5a. *Acacia melanoxylon – Gahnia sieberiana* Open Swamp Forest

Dominated by *Acacia melanoxylon* with occasional *Eucalyptus globulus* to 25 m with >25% cover (Appendix 1). The ground layer is dominated by *Gahnia sieberiana* (20–40% cover), a sparse cover of grasses (*Poa helmsii*, *Poa labillardieri*, *Microlaena stipoides*) and small sedge or herb species. *Baumea rubiginosa* is occasionally locally dominant. *Baeckea utilis* may also be present and *Eucalyptus camphora* is an occasional co-dominant.

Open Swamp Forest is confined to steeper slopes and gullies at higher elevations (around 600 m) in the north Strathbogies. Sites are on gully slopes or drainage lines and are topo-soligenous. This community is likely to be a remnant vegetation type formerly more widespread in drainage lines.

### Group 5b. *Acacia melanoxylon – Eucalyptus camphora* Swamp Woodland

Recorded from a single quadrat within state forest but distinguished from groups 5a and 5c by a higher cover of bracken and lower cover of native herbs and small sedges (Appendix 1). Swamp Woodland consists is dominated by *Acacia melanoxylon* and *Eucalyptus camphora* to 25 m (20% cover) with a moderately dense ground layer (50% cover) dominated by *Carex appressa*, *Carex fascicularis*, *Blechnum nudum*, *Pteridium esculentum*, *Poa helmsii* and remnant *Dicksonia antarctica*.

This community was recorded on a soligenous gentle slope in one of the most elevated parts of the study area (595 m).

The quadrat is a rare example of *Eucalyptus camphora* forest unmodified by agricultural practices, although past disturbances are likely to have included selective logging in the surrounding dry sclerophyll forest and higher fire frequencies than in agricultural land. Grass and other graminoid cover is lower overall (20% *cf.* 40%) and bracken cover higher (10% *cf.* <1%) than in the previous group.

### Group 5c. *Acacia melanoxylon – Carex appressa* Open Swamp Forest

At most sites this community consists of *Acacia melanoxlyon* (to 20 m) with *Eucalyptus camphora*, *Leptospermum lanigerum* and *Dicksonia antarctica* at some sites (Appendix 1). Canopy cover is generally >10% but may be lower at disturbed sites. The understorey is dominated by a dense cover of *Carex appressa* (70–90%) and minor species *Cyperus lucidus* and/or *Blechnum* spp., with a sparse cover (<5%) of introduced species such as *Holcus lanatus* and *Lotus corniculatus*.

Open Swamp Forest occurred in gullies and vales at higher altitudes across the study area. Sites were structurally modified and reasonably species poor, but had relatively low weed cover and were thus considered to be in moderate to good condition. Two sites had been fenced for five years.

### Group 6. *Eucalyptus camphora – Leptospermum lanigerum* Thicket Swamp Forest

This group is distinguished by well-developed stands of *Leptospermum lanigerum* (>50% cover, to 10 m high) with *Eucalyptus camphora* or occasionally *Acacia melanoxylon* emergent above the dense canopy, generally sparse (<10% cover) but occasionally with up to 25% cover (Appendix 1). The understorey is generally quite open, and mainly consists of a sparse cover of younger *Leptospermum lanigerum* individuals, and blackberry at some sites. The ground layer is open to moderately dense (15–50% cover) and is made up of sedges, grasses and ferns which may include *Gahnia sieberiana*, *Poa helmsii*, *Blechnum minus*, and a sparse cover of *Baumea rubiginosa* or occasionally *Gleichenia microphylla*. Minor ground layer species include a mix of small sedges and herbs (e.g. *Eleocharis gracilis*, *Isolepis* spp., *Acaena novae–zelandiae*, *Gonocarpus micranthus* and exotics (e.g. *Hypochaeris radicata*, *Lotus corniculatus*, *Holcus lanatus*).

The community appears to be confined to cooler, high rainfall areas (500–570 m) on slopes to the north of the study area.

Referable to Swamp Scrub (EVC# 53), Riparian Scrub (EVC# 191) with elements of Fern Swamp.

### Group 7. *Eucalyptus camphora* Swamp Woodland

Nearly a third of quadrats (22) were allocated to this group, which contained a degree of floristic and structural variation among quadrats. However, all quadrats were characterised by a moderately dense to dense cover (>50%) of *Baumea rubiginosa*, or less frequently *Baumea planifolia*.

Referable to Swampy Woodland (EVC# 937).

### 7a. *Eucalyptus camphora – Baumea rubiginosa* Swamp Woodland

This vegetation community is characterised by very wet peat with well-developed organic content (Table 2) and a sparse to moderate cover (5–50%) of trees and/or tall shrubs (5–20 m) consisting of *Eucalyptus camphora*, *Leptospermum lanigerum* or occasionally *Baeckea utilis* at drier sites (Appendix 1). The second stratum consists of a sparse cover (< 25%) of smaller shrubs (< 2m high), typically *Leptospermum continentale* and/or *Baeckea utilis*. *Baumea rubiginosa* forms a dense ground layer (50–100%) and *Phragmites australis* may develop on very wet sites excluded from grazing. Minor ground layer species are *Blechnum minus*, *Hydrocotyle* spp., *Epilobium* spp., *Gonocarpus micranthus* and small graminoids such as *Juncus* spp. and *Eleocharis gracilis*. Introduced exotics were generally less abundant than in group 7b.

*Eucalyptus camphora – Baumea rubiginosa* Swamp Woodland was recorded in the central wetland zone at higher elevations (440 m–590 m). Quadrats were higher in native species richness than group 7b (17 *cf.* 10), with lower mean cover of weeds (7% *cf.* 20% cover). Almost all sites were recorded on gentle to steep soligenous slopes and occasionally in vales and gullies.

### 7b. *Baumea rubiginosa* or *Baumea planifolia* Closed Sedgeland

This community is lacking in trees, but may occasionally include a sparse cover (<10%) of tall shrubs (*Leptospermum continentale* and/or *Baeckea utilis).* It is dominated by tall, moderately dense to dense swards (>50%) of *Baumea rubiginosa* which may grow to 2 m high (Appendix 1). *Baumea planifolia* is dominant at some sites, mostly to the north of the study area. Ground layer species generally include grasses, other small graminoids and herbs such as *Poa helmsii*, *Eleocharis gracilis*, *Juncus* spp., *Epilobium* spp. and occasionally *Sphagnum* spp. Introduced exotic species *Holcus lanatus*, *Hypochaeris radicata* and *Anthoxanthum odoratum* are also prominent in the ground layer.

*Baumea rubiginosa/Baumea planifolia* Closed Sedgeland occurs at higher elevations (420–590 m) in the central, mid and outer wetland zones. Sites were mostly located on gentle to steep soligenous slopes, mounds and occasionally in vales.

### Group 8. *Elaeocharis gracilis* Low Sedgeland

Low Sedgeland is dominated by *Eleocharis gracilis* and a suite of small sedges and herbs (60–80% combined cover) forming a low (<0.3 m) turf (Appendix 1). Associated species typically include *Hydrocotyle sibthorpioides*, *Epilobium* spp., *Drosera peltata*, *Schoenus maschalinus*, *Schoenus apogon*, *Isolepis subtillissima*, *Isolepis inundata*, *Juncus articulatus*, *Juncus planifolius* and *Lotus corniculatus*. *Holcus lanatus* may be locally dominant at the spring vent.

Sites occur on waterlogged, soligenous spring-fed mounds with high organic content (Table 2). The community is mainly distributed in cooler, high rainfall areas but is occasionally

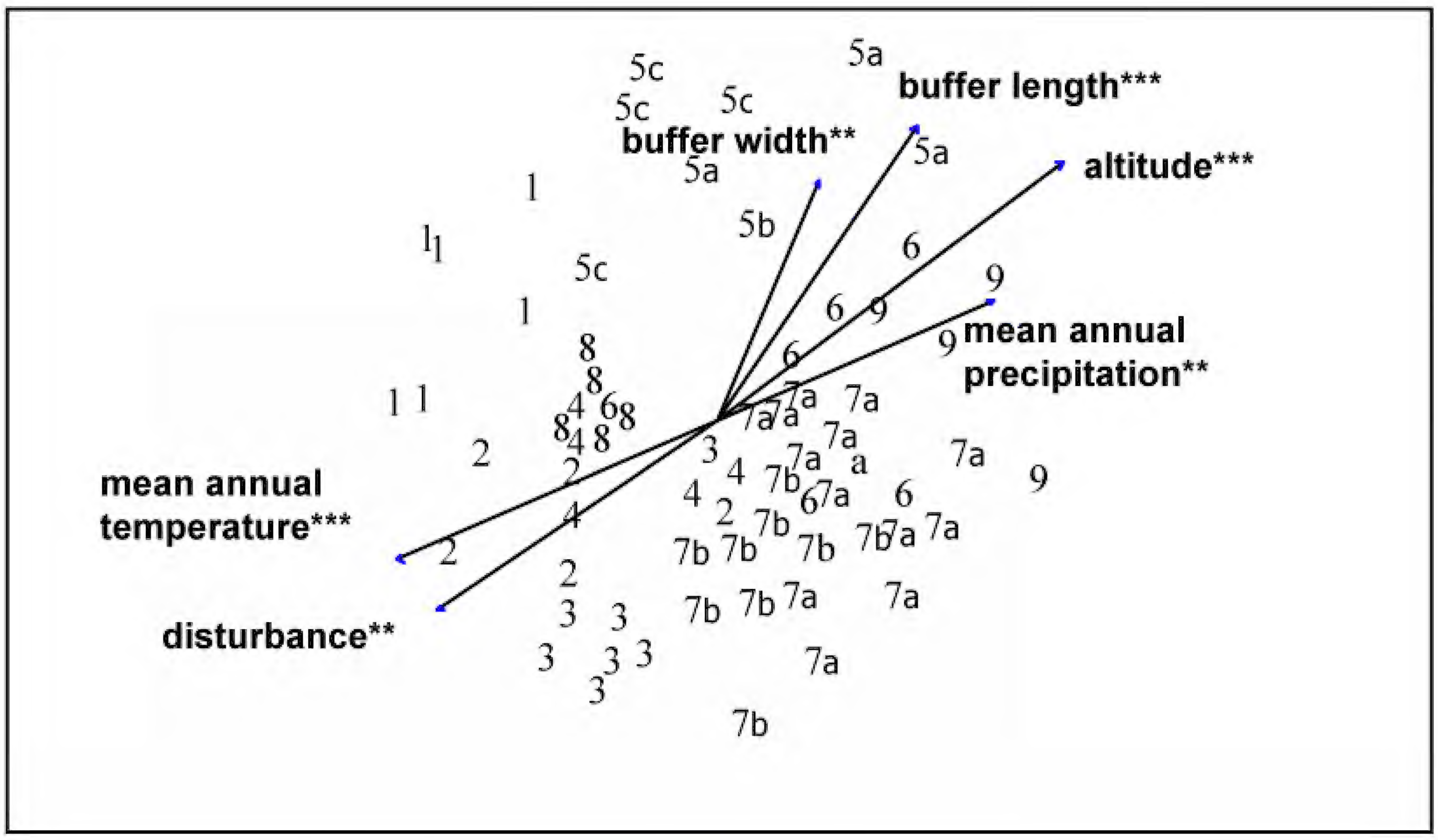

**Fig. 3.** Distribution of quadrats within the 3-dimensional ordination space, dimensions 1 and 2.
Points are labelled by cluster group membership and vectors of maximum correlation; fitted vectors correlation co-efficients (r2) and statistical significance. ** <0.01; *** < 0.001. Vector lengths are proportional to strength of correlation.

found at lower altitudes (350–570 m). Mounds occur within forest and in open paddocks.

No referable EVC.

### Group 9. *Eucalyptus camphora – Acacia melanoxylon – Gleichenia microphylla* Swamp Woodland

This group consists of species rich sites with an understorey characterised by a dense cover of *Gleichenia microphylla* (40–80%). Other understorey species may include *Baumea rubiginosa* and *Pteridium esculentum. Acacia melanoxylon* and/or *Eucalyptus camphora* are the dominant tree species (3–20 m, <25% cover) and *Leptospermum lanigerum* may be locally dominant in the second stratum (Appendix 1). The ground layer consists of a very sparse cover of small sedges, herbs and grasses but *Holcus lanatus* and other exotics commonly recorded elsewhere in the study area are sparse.

Sites are located on slopes in cool, elevated areas (520–620 m). All sites are on gentle to steep soligenous slopes but are showing signs of deterioration, as evidenced by large areas of *Gleichenia* either dead or dying.

Referable to Swampy Woodland (EVC# 937).

NMDS attained a minimum stress of 0.17 in three dimensions. In the plane bounded by dimensions 1 and 2, floristic composition was correlated with variables related to climate and disturbance (Figure 3). The least disturbed sites, with fewer tracks, less pugging and lower weed cover, consisted of forest and woodland which were better buffered by native vegetation, and situated in cooler, more elevated locations than disturbed sites. These were *Acacia melanoxylon* Swamp Forest (Group 5), *Eucalyptus camphora – Leptospermum lanigerum* Open Swamp Forest (Group 6) and *Eucalyptus camphora – Acacia melanoxylon – Gleichenia microphylla* Swamp Woodland (Group 9).

At the opposite end of this trend were treeless sites with higher mean annual temperatures at lower elevations and sites to the north of the study area with higher levels of disturbance. These groups were *Juncus sarophorus* Sedgeland (Group 2), *Baeckea utilis* Shrubland (Group 3) and *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland (Group 4).

A third compositional trend (dimensions 1 and 3, Figure 4), was correlated with the vector for native species richness. Quadrats with high species richness mainly belonged to Group 6 (*Eucalyptus camphora – Leptospermum lanigerum* Open Swamp Forest) and Group 9 (*Eucalyptus camphora – Acacia melanoxylon – Gleichenia microphylla* Swamp Woodland). However, while the vector was highly significant in relation to site positions on the ordination, the raw data indicated that the relationship between richness and vegetation groups was weaker. There was also a weak correlation between floristic composition and the number of years that some of these sites had been fenced. This suggests that stock exclusion may have positive benefits; however, almost all sites that had been fenced for five or more years were located to the north of the study area on soils with relatively low (< 60%) moisture content, implying that compositional variation may be attributable in part, to establishment of species suited to drier soils.

The relationship between floristic composition and distance upslope to a dam was also weakly significant (Figure 4). While dams were further upslope (> 150 m) of quadrats in Group 1 (*Phragmites* Reedland) and Group 2 (*Juncus* Sedgeland), inspection of the raw data revealed that there was no consistent relationship between this variable and other groups.

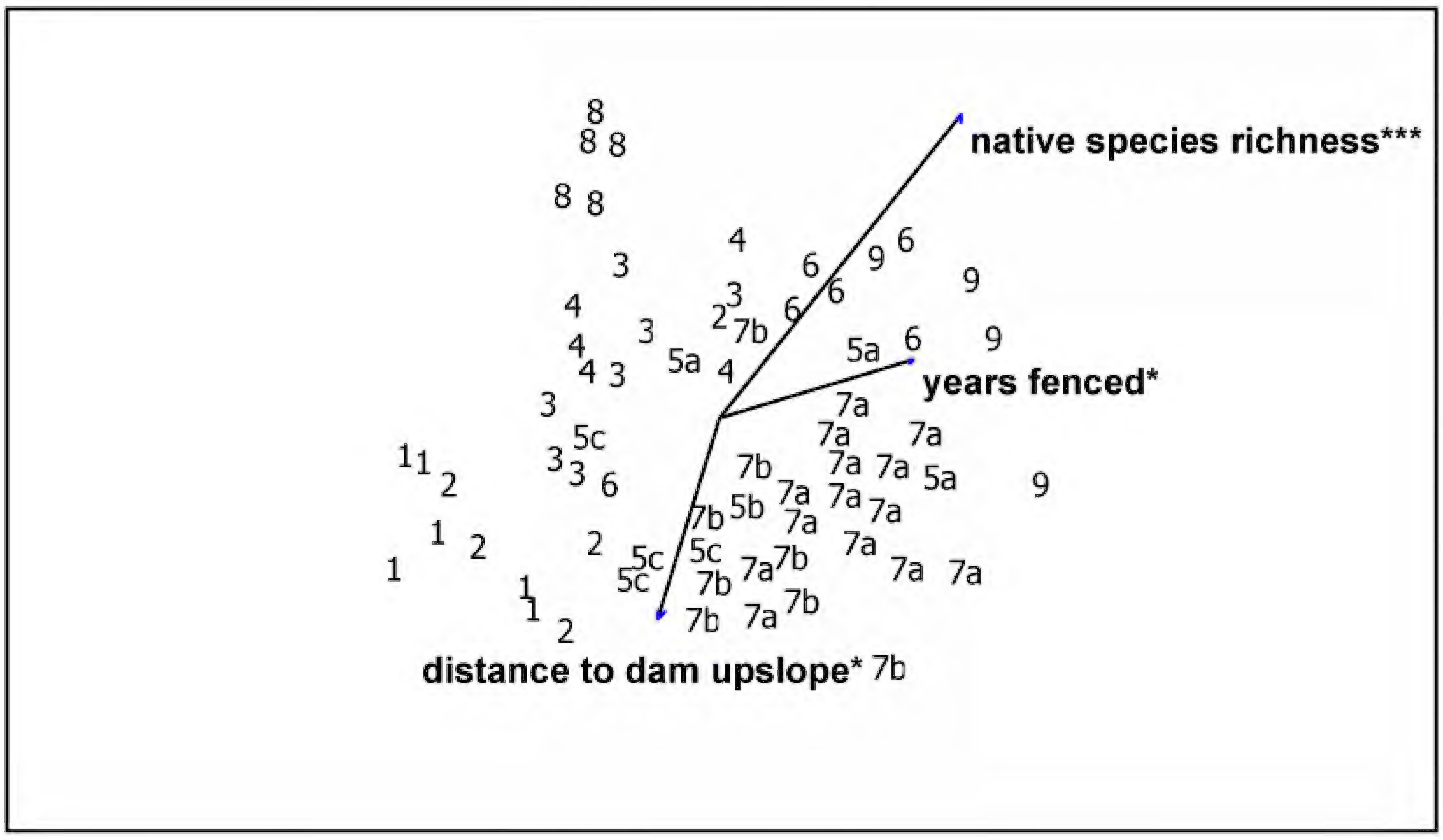

**Fig. 4.** Distribution of quadrats within the 3-dimensional ordination space, dimensions 1 and 3.
Points are labelled by cluster group membership and vectors of maximum correlation; fitted vectors correlation co-efficients ($r^2$) and statistical significance. * < 0.05; *** < 0.001. Vector lengths are proportional to strength of correlation.

## Current and potential threats

### *Habitat destruction and degradation*

*Changes in land cover*: trends in land use change included an increase in the area of farm land converted to hardwood or softwood plantations, viticulture and horticulture (10% of sites visited).

*Grazing*: only seven quadrats were currently grazed (<10%). Pugging and tracks were the most frequently recorded threat, but severity was generally low with the exception of cleared mound areas or very wet areas. Grazing was also the most common land use within 250 m of wetlands (82%).

*Weed invasion*: high levels of weed cover were recorded. *Holcus lanatus*, *Lotus corniculatus* and *Hypochaeris radicata* were the three most frequently recorded weeds, occurring in more than 80% of quadrats. *Rubus* spp. (blackberry) were recorded in approximately 50% of wetlands but were rarely abundant, probably because of high investment in control measures by landowners.

*Earthworks and extraction*: excavation in the form of dams or channels or water extraction via pipes was observed in 30% of the wetlands visited. Landforming (e.g. embankments) was observed less frequently (< 10%) and was generally associated with roadworks or redirection of water (e.g. around culverts).

### *Dysfunction of physical and biological processes*

*Reduction in wetland area*: 60% of wetlands were assessed as showing signs of drying out, defined as having more than 50% of their area consisting of dry or damp soil (as distinct from saturated or waterlogged soil). This observation was made in another guise by long-term landowners who frequently commented on the extent to which areas of land, previously boggy 20 years ago, were now traversable in a vehicle. At least some vegetation zonation (> 25% intact) was detected at one third of wetlands. However, almost 50% of wetlands assessed showed no sign of zonation, with a small proportion having 10–20% of the presumably original vegetation zones remaining.

*Fragmentation*: assumed loss of connectivity was observed in 40% of wetland systems, as a result of general land clearing.

*Degradation and clearing of buffers*: vegetation with a significant component (> 25%) of native species surrounding wetlands was absent from or sparse (< 0.1 ha) in 60% of wetlands. Of the remaining wetlands, only one site (on public land) was completely surrounded by forest and there were few wetlands (< 20% of sites) with buffers > 0.5 ha.

### *Changes to disturbance regimes*

*Increased interspecific competition*: Sedge cover in excess of 50% was measured in 37% of quadrats and greater than 75% cover was measured in 18% of quadrats (predominantly *Baumea rubiginosa* or *Eleocharis gracilis*).

*Fire*: charcoal was recorded in 52% of quadrats, indicating that fire occurred historically throughout the study area.

## Discussion

### *Floristic composition*

Most vegetation communities were referable to published EVCs with the exception of group 8 (*Elaeocharis gracilis* Low Sedgeland), which was confined to an undescribed landform element (spring-fed mounds) in Victoria. None of the other floristic groups identified by clustering was confined to any particular hydrogeomorphic class.

We did not attempt to describe vegetation zonation. Intact zones were mostly indistinguishable in the field, having been disrupted as a consequence of various disturbances since European settlement, altered hydrological states and subsequent changes to vegetation structure and composition. The lack of clear or consistent delineation between floristic groups on the basis of substrate properties, landscape setting, or other variables is not surprising. Rather, the results describe the floristic assemblages currently present within the landscape, across a range of elevations and degrees of disturbance. The results suggest that hydrogeomorphic classification is unlikely to provide a suitable basis for conservation and management of remnant vegetation because landform setting and hydrologic dynamics alone do not differentiate the range of floristic assemblages present within these wetlands at the scale the study was conducted.

The structural and floristic variation within the range of landform settings and differing management histories across the study area make it virtually impossible to reconstruct the pre European vegetation and there were few if any examples of the presumed original forests. It seems reasonably likely that the extant vegetation is derivative from wet forest, swamp woodlands and shrublands or thickets dominated by *Acacia melanoxylon*, *Eucalyptus camphora*, *Leptospermum lanigerum*, *Leptospermum continentale* and/or *Baeckea utilis*, with a groundlayer consisting mainly of sedges (Cyperaceae) but including a range of forbs and at some sites, *Sphagnum* spp.

Sediment cores showed a distinct zone separating peat and clay layers but which frequently contained charcoal particles throughout, a pattern which was remarkably consistent all over the study area. This may indicate some sudden environmental change such as the arrival of Europeans who used fire to clear vegetation and to provide green feed for sheep (White *et al*. 1990). As a consequence, peat development may be relatively recent, with water tables rising in response to tree removal. Recent palynological work in three wetlands in the southern part of the study area dated these sites between 1,100 years to a mere 100 years old, lending support to the notion that some wetlands in the study area are an artefact of vegetation clearing (Gubbins 2010). The transformation of swamp forest to sedgeland has also been seen after burning in some northern hemisphere wetlands (von Grootjans *et al*. 2005). Evidence of charcoal is common in swamps (Whinam & Hope 2005) and charcoal was also frequently recorded throughout the deeper clay layers, suggesting that fire has also occurred (either naturally or as a result of Aboriginal burning) over the longer-term.

Current variation in vegetation composition of spring wetlands on the Strathbogie plateau is related to climate, intensity of land use and management. The least disturbed sites (lower weed cover, less soil disturbance) consisted of forested vegetation which was more likely to occur at higher elevations where grazing pressure appears to have been historically less intense, occurred in State Forest or was confined to relatively steep slopes not targeted for clearing. All of these sites were well buffered by native vegetation and most were distant from upslope dams although the vector for the latter variable was relatively weak.

Treeless vegetation (Groups 2, 3, 4 and 8) was the most highly disturbed and was often associated with wetlands in open paddocks where the ground was pugged and the vegetation had been grazed down to a short turf. These sites undoubtedly represent the vegetation which has been most highly modified since European settlement. Nonetheless, native species were well represented in some of these groups, notably groups 3, 4 and 8. This implies a functional shift in the vegetation, whereby an array of minor species has been able to flourish with increased light availability and control of competitors under a regime of grazing.

There was little or no evidence in the data that water extraction via dams and known bores was a significant driver of vegetation composition at the quadrat scale; indeed, there were few bores mapped within 100 m of any study site and only 149 licensed bores across the Strathbogie plateau, equivalent to a bore density of approximately 1 per 6 km$^2$, estimated as less than 5% of a base-level groundwater discharge rate (Stewardson *et al.* 2009).

Soil properties, including moisture content, were not related to variation in floristic composition and were not significantly correlated with disturbance. This tends to suggest that land use has affected the vegetation more directly through clearing and reducing structural complexity, than indirectly through hydrological changes. However, sampling was focussed in the wetter, central wetland areas, where the effects of drying are less likely to be detectable than in the outer wetland areas. Outer zones with shallower soils and greater seasonality in moisture levels would be expected to show trends toward drying earlier than central zones, and might be adversely impacted by any decrease in water availability.

A more accurate inventory of the current number and extent of bores and dams, and the total volumes of water extraction including groundwater discharge rates and both the distribution and pumping rates of groundwater bores (Stewardson *et al.* 2009) may provide more information. One site was close to Dropmore Spring, used since 1931 and with a flow of 0.03 L/s; however, no comparable data were available for other springs or bores. Stewardson *et al.* (2009) concluded that on average, the influence of groundwater extractions on spring discharge is likely to be small. Thus, the most likely explanation for soil drying is reduced spring discharge in recent years primarily as a consequence of the sequence of lower annual rainfall totals experienced in the Strathbogie Ranges over the last decade (Stewardson *et al.* 2009).

We also observed obvious signs of soils drying out at forest/woodland sites which were among some of the least disturbed and were excluded from stock grazing, but had clearly deteriorated in recent years. These sites were situated on slope breaks with ground layers characterised mainly by large dead or dying colonies of *Gleichenia microphylla* or by dense stands of *Gahnia sieberiana* and at one site, remnant *Sphagnum*. However, it is difficult to determine to what extent loss of soil moisture and wetland contraction is attributable to the dam above or to longer-term climatic changes. Nevertheless, these soil drying trends were indicated at the scale of overall site condition. This is further supported by the results of the mapping, which determined (conservatively) nearly a 60% loss of wetland vegetation, as indicated by the extent of 'remnant' vegetation in paddocks.

### *Threats and management*

Mapping revealed that wetlands within the study area are likely to have decreased, conservatively, by nearly two thirds of their original extent, as a result of historical clearing and grazing (and possibly interruptions to hydrology). The main impact on vegetation is likely to be loss of vegetation zonation and replacement of indigenous wetland species by native or introduced dryland species. The wetlands surveyed were vulnerable to a range of threats which could be grouped into three categories: habitat destruction and degradation, dysfunction of physical and biological processes and changes to disturbance regimes.

The major consequences of grazing are eutrophication resulting from pollution by urine and faeces, disturbance and destruction of peat, selective grazing of palatable species, a reduction in the area of soil available for survival and reproduction of native species, and conditions more suitable for establishment of weeds. Ubiquitous exotic pasture species have virtually replaced the ground layer at many sites, favoured by high soil moisture, soil disturbance and increased nutrient levels from broadacre fertilising.

The specific measurement of seasonal inundation was beyond the scope of the study, although many landowners drew attention to this as a likely threat. Loss of the natural range of water regimes (extent and degree of saturation) will further exacerbate the loss of vegetation zonation or loss of understorey dominants which characterises wetland systems, and which has already occurred at most sites. This may result from a long-term decrease in precipitation, from human-induced changes in the surrounding landscape, or from both of these factors.

The role of native vegetation buffers is likely to be most beneficial in maintaining connectivity, reducing access to stock, improving water quality by filtering surface run-off, and making an important contribution to local biodiversity. Buffers consisted of forested vegetation as well as native grassland which had established when wetlands had been fenced off to exclude stock. Some were dominated by an array of native species, in particular *Themeda australis,* but this depended on past land management such as fertilizer use and extent of ploughing. These buffers require management in the form of sheep grazing or preferably burning, to maintain the somewhat serendipitous establishment of native vegetation that has occurred around wetland sites.

An emerging industry on the Strathbogie plateau is conversion of farmland to blue gum plantations. The replacement of herbaceous vegetation with monocultures may have potential to disrupt wetland hydrology and some biological interactions. We speculate that impacts might include a loss of pollinators, an increase in predators and herbivores, loss of resilience to disease and pathogens (Auld & Keith 2008), or a reduction in ground water availability through transpiration.

Recent conservation efforts have focussed on fencing wetlands to exclude livestock from some of the wetlands, almost all of which occur on private property. An unforeseen consequence of exclusion has been an increase in dominance of large, highly competitive reeds and sedges (e.g. *Phragmites australis*, *Baumea rubiginosa*). Ongoing risks to vegetation quality include increased interspecific competition leading to exclusion of other species and reduction in species diversity, particularly minor or rare inter-tussock species such as *Eriocaulon scariosum* (Department of Sustainability and Environment 2005). Advantages at these sites include provision of habitat protection from predators for native fauna by dense ground layers.

Recent experimental trials have found that regular biomass removal by grazing, burning or slashing is likely to be necessary to control large sedges and weeds but restoration of species richness in Closed Sedgeland presents a substantial challenge (Coates & Tolsma 2012). Most wetlands are highly modified and it will be futile to attempt to restore them to some idealised, pre-European state. Ongoing experimental trials over timeframes of three to five years are still needed to determine specific management prescriptions.

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## References

Ashton DH & Hargreaves GR (1983). Dynamics of sub-alpine vegetation at Echo Flat, Lake Mountain, Victoria. *Proceedings of the Ecological Society of Australia* 12: 35–60.

Auld TD & Keith DA (2008). Dealing with threats: Integrating science and management. *Ecological Management and Restoration* 10 Supplement 1: 79–87.

Blyth J & English V (1996). Endangered – Tumulus Springs. *Landscope* 11: 47.Bureau of Meteorology (online) http://www.bom.gov.au/climate/averages/tables/cw_082042.shtml [last visited 05/05/12].

Carr GW, Moysey ED, Mathews S, Frood D, White M, Griffioen P, Morgan J & Rosengren N (2006). The location of Spring Soak and Peatland wetlands in the Goulburn Broken Catchment – Wetland Implemetation Plan Stage. Unpublished report to the Goulburn Broken Catchment Management Authority.

Coates F & Tolsma A (2012). An investigation of spring wetland management techniques. Unpublished report to the Goulburn Broken Catchment Management Authority, Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria.

Coates F, Cullen P, Zimmer H & Shannon J (2012). *How snow gum forests and sub-alpine peatlands recover after fire: Black Saturday Victoria 2009 – Natural values fire recovery program.* Department of Sustainability and Environment, Heidelberg, Victoria.

Dean WE Jr (1974). Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods. *Journal of Sedimentary Petrology* 44: 242–248.

Department of Sustainability and Environment (2005) Advisory List of Rare or Threatened Plants in Victoria – 2005. Victorian. Department of Sustainability and Environment, East Melbourne, Victoria.

Department of Sustainability and Environment (2006). *Index of Wetland Condition. Assessment of wetland vegetation. Update– March 2006* (Department of Sustainability and Environment: Melbourne).

Department of Sustainability and Environment (2012). A Field Guide to Victorian Wetland Ecological Classes for the Index of Wetland Condition, 2nd edition. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria.

Eamus D, Froend R, Loomes R., Hose G & Murray B (2006). A functional methodology for determining groundwater regime needed to maintain the health of groundwater-dependent vegetation. *Australian Journal of Botany*, 54: 97–114.

Faith DP, Minchin PR & Belbin L (1987). Compositional dissimilarity as a robust measure of ecological distance: a theoretical model and computer simulations. *Vegetatio* 69: 57–68.

Fensham RJ & Fairfax RJ (2003). Spring wetlands of the Great Artesian Basin, Queensland, Australia. *Wetlands Ecology and Management* 11: 343–362.

Fensham RJ & Price RJ (2004). Ranking spring wetlands in the Great Artesian Basin of Australia using endemicity and isolation of plant species. *Biological Conservation* 119: 41–50.

Fensham RJ, Fairfax RJ, Pocknee D & Kelley J (2004*a*). Vegetation patterns of permanent spring wetlands of arid Australia. *Australian Journal of Botany* 52: 719–728.

Fensham RJ, Fairfax RJ & Sharpe PR (2004*b*). Spring wetlands in seasonally arid Queensland: floristics, environmental relations, classification and conservation values. *Australian Journal of Botany* 52: 583–595.

Gubbins W (2010). *Vegetation Change and the Ecological Effects of European settlement: A Palynological and Historical Investigation of the Strathbogie Ranges*, Victoria. BA Honours Thesis, the University of Melbourne.

Hatton T & Evans R (1998). *Dependence of ecosystems on groundwater and its significance to Australia*. Occasional Paper No. 12/98, Land and Water Resources Research & Development Corporation, Canberra.

Hope GS, Nanson R & Jones P (2011). The peat-forming bogs and fens of the Snowy Mountains of New South Wales. Office of Heritage and the Environment, New South Wales Government, Queanbeyan.

Houlder D, Hutchinson M, Nix H & McMahon J (2005). *ANUCLIM Version 5.1* (Centre for Resources and Environmental Studies: The Australian National University, Canberra).

Kantvilas G & Minchin P (1989). An analysis of epiphytic lichen communities in Tasmanian cool temperate rainforest. *Vegetatio* 84: 99–112.

Keddy PA (2010). *Wetland Ecology: Principles and Conservation* (Cambridge University Press).

Mackrell CW (1977). *Strathbogie Centenary: 1977–1977: A History of Strathbogie* (Strathbogie Centenary Committee).

McCall H (1982). *Highlands 1882–1892* (Wangaratta Audio Visual Branch).

McCune B & Grace JB (2002). *Analysis of Ecological Communities*. MJM Software Design (Gleneden Beach: Oregon, USA).

Minitab (2010). *Minitab® Statistical Software Release 16.1.0* (Minitab Inc: State College, Pennsylvania).

Mitsch WJ & Gosselink JG (2007). *Wetlands* (John Wiley & Sons, Inc).

Nix HA & Busby J (1986). *BIOCLIM: A bioclimatic analysis and prediction system* (Division of Land and Water Resources, CSIRO: Canberra).

Oksanen J (2011). *Multivariate Analysis of Ecological Communities in R: Vegan Tutorial*. http://cc.oulu.fi/~jarioksa/opetus/metodi/vegantutor.pdf [last visited 05/05/212].

Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH & Wagner H (2012). Vegan: Community Ecology Package. R package version 2.1–14/r2120. http://R-Forge.R-project.org/projects/vegan/ [last visited 23/03/12].

Phillips GN, Ely KS, Hergt JM, Cownley DG, Paul B & Dickins C (2002). 3–dimensional geometry of the Strathbogie batholith. In *Victoria Undercover: Benalla 2002 Conference Proceedings and Field guide: Collaborative Geoscience in Northern Victoria* (Phillips, G.N. and Ely, K.S. eds), CSIRO Publishing, Collingwood. pp. 55–60.

Raulings EJ, Morris K, Roache MC & Boon PI (2010). The importance of water regimes operating at small spatial scales for the diversity and structure of wetland vegetation. *Freshwater Biology* 55: 701–715.

Ramsar Convention Bureau (1991). *Proceedings of the 4th Meeting of the Conference of Contracting Parties. Montreux, Switzerland.* (Ramsar Convention Bureau: Gland, Switzerland).

R Development Core Team (2011). *R: A language and environment for statistical computing. R Foundation for Statistical Computing*. http://www.R-project.org/ [last visited 23/03/12].

Robertson HA & Fitzsimons JA (2004). Hydrology or floristics? Mapping and classification of wetlands in Victoria, Australia, and implications for conservation planning. *Environmental Management* 34: 499–507.

Ryadin H & Jeglum J (2006). *The Biology of Peatlands* (Oxford University Press: Oxford, UK).

Semeniuk V & Semeniuk CA (1997). A geomorphic approach to global classification for natural inland wetlands and rationalisation of the system used by the Ramsar Convention – a discussion. *Wetlands Ecology and Management* 5: 145–158.

Specht RL, Roe EM & Broughton VH (1974). Conservation of major plant communities in Australia and Papua New Guinea. *Australian Journal of Botany Suppl. Series No. 7.*

Stewardson M, Western A & Wallis E (2009). The Hydrology of Wetlands in the Strathbogie Ranges. Unpublished report to the Goulburn Broken Catchment Management Authority. Department of Civil and Environmental Engineering, The University of Melbourne.

Tomita K (2008). Relationships among vegetation, landform, and sediments in spring-fed wetlands on the Owari Hills and Chita Hills, central Japan. *Geographical Review of Japan* 81: 470–490.

Venables WN & Ripley BD (2002). *Modern Applied Statistics with S*. Fourth Edition (Springer: New York).

von Grootjans A, Alserda A, Bekker R, Janakova M, Kemmers R, Madaras M, Stanova V, Ripka J, Van Delft B & Wolejko L (2005). In *Mires–from Siberia to Tierra del Fuego* (Steiner, G.M. ed), Stapfia 85, Linz, Austria. pp. 97–116.

Wahren C-HA, Williams R & Papst WA (1999). Alpine and sub-alpine wetland vegetation on the Bogong High Plains, south-eastern Australia. *Australian Journal of Botany* 47: 165–88.

Walsh NG & Stajsic V (2007). *A Census of the Vascular Plants of Victoria*. Eighth Edition (Royal Botanic Gardens: Melbourne).

Whinam J & Hope G (2005). The Peatlands of the Australasian Region. In *Mires–from Siberia to Tierra del Fuego* (Steiner, G.M. ed), Stapfia 85: Linz, Austria. pp. 397–434.

Whinam J, Chilcott NM & Morgan J (2003). Floristic composition and environmental relationships of *Sphagnum*-dominated communities in Victoria. *Cunninghamia* 8: 162–174.

White LA, Gigliotti F & Cook PD (eds) (1990). *A Reconnaissance Survey of the Catchment of the Middle Reaches of the Goulburn River*. (Land Protection Division: Dept. of Conservation, Forests & Lands, Victoria).

White M, Murphy AH & Downe J (2006). *National Recovery Plan for the Buxton Gum Eucalyptus crenulata* (Department of Sustainability and Environment: Melbourne).

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## Appendix 1. Examples of vegetation groups and distribution of frequent species in quadrats

Cover–abundance classes:
1 = 0.5–1%; 2 = 1–5%; 3 = 5–15%; 4 = 15–25%; 5 = 25–50%; 6 = 50–75%; 7 = 75–100%.
Introduced species are indicated by '*'.

### Group 1. *Phragmites australis* Reedland

| | |
|---|---|
| **Anthoxanthum odoratum* | 010001 |
| *Baumea rubiginosa* | 000211 |
| *Blechnum minus* | 000011 |
| *Blechnum nudum* | 000001 |
| *Callitriche stagnalis* | 000001 |
| *Carex appressa* | 003550 |
| *Carex fascicularis* | 000511 |
| *Carex gaudichaudiana* | 130000 |
| **Cirsium vulgare* | 110100 |
| *Cyperus lucidus* | 010000 |
| *Dicksonia antarctica* | 000001 |
| *Epilobium pallidiflorum* | 001010 |
| *Eucalyptus camphora* | 000020 |
| *Galium australe* | 101101 |
| *Glyceria australis* | 311011 |
| **Glyceria maxima* | 003000 |
| **Holcus lanatus* | 542301 |
| *Isolepis inundata* | 000001 |
| **Juncus bufonius* | 000001 |
| *Juncus planifolius* | 000001 |
| *Juncus sarophorus* | 320001 |
| *Leptospermum lanigerum* | 000010 |
| **Lotus corniculatus* | 031111 |
| **Mimulus moschatus* | 000001 |
| *Phragmites australis* | 657556 |
| *Poa helmsii* | 000100 |
| *Pteridium esculentum* | 001001 |
| **Rubus fruticosus* | 001001 |
| **Rumex crispus* | 110000 |
| *Stellaria angustifolia* | 000001 |
| *Epilobium* sp. | 001001 |
| *Isolepis* sp. | 000001 |

### Group 2. *Juncus sarophorus – Carex appressa* Sedgeland

| | |
|---|---|
| *Acacia melanoxylon* | 00010 |
| *Acaena novae–zelandiae* | 00111 |
| **Anthoxanthum odoratum* | 32331 |
| **Briza minor* | 00001 |
| *Baumea rubiginosa* | 02023 |
| *Blechnum minus* | 00010 |
| *Callitriche stagnalis* | 10000 |
| *Carex appressa* | 01353 |
| *Carex gaudichaudiana* | 20000 |
| *Centella cordifolia* | 00001 |
| **Cirsium vulgare* | 11000 |
| *Cyperus lucidus* | 10012 |
| *Eleocharis gracilis* | 00011 |
| *Epilobium billardierianum subsp. hydrophilum* | 00010 |
| *Epilobium pallidiflorum* | 10300 |
| *Eucalyptus camphora* | 00010 |
| *Glyceria australis* | 10000 |
| *Gonocarpus micranthus* | 00010 |
| **Holcus lanatus* | 51534 |
| *Hydrocotyle sibthorpioides* | 00001 |
| **Hypochaeris radicata* | 01112 |
| *Isotoma fluviatilis* | 00101 |
| *Juncus planifolius* | 00011 |
| *Juncus sarophorus* | 55234 |
| *Leptospermum lanigerum* | 00020 |
| **Lotus corniculatus* | 21121 |
| *Luzula meridionalis* | 00010 |
| **Mimulus moschatus* | 00010 |
| *Phragmites australis* | 01000 |
| *Poa helmsii* | 02043 |
| *Poa labillardieri* | 00001 |
| *Ranunculus glabrifolius* | 00001 |
| **Rubus fruticosus* | 00001 |
| **Rumex crispus* | 10000 |
| *Senecio* sp. | 00100 |
| **Trifolium dubium* | 00001 |
| *Utricularia dichotoma* | 00100 |

## Group 3. *Baeckea utilis* Shrubland

| | |
|---|---|
| *Acacia melanoxylon* | 0100001 |
| **Anthoxanthum odoratum* | 3134333 |
| *Arthropodium milleflorum* | 1111000 |
| *Baeckea utilis* | 5653673 |
| *Baumea rubiginosa* | 0222223 |
| *Blechnum minus* | 0000011 |
| *Callitriche stagnalis* | 0011010 |
| *Carex appressa* | 0001010 |
| *Carex gaudichaudiana* | 1040001 |
| *Drosera peltata* | 0111001 |
| *Eleocharis gracilis* | 0131015 |
| *Epacris breviflora* | 2010330 |
| *Eucalyptus camphora* | 0100002 |
| *Euchiton involucratus* | 0011011 |
| *Geranium potentilloides* | 0001001 |
| *Gleichenia microphylla* | 0000001 |
| *Gonocarpus micranthus* | 1121300 |
| *Goodenia elongata* | 1001000 |
| **Gratiola peruviana* | 0010010 |
| *Histiopteris incisa* | 0000101 |
| **Holcus lanatus* | 3513322 |
| *Hydrocotyle hirta* | 1100000 |
| *Hydrocotyle sibthorpioides* | 0001011 |
| *Hypericum japonicum* | 0011001 |
| **Hypochaeris radicata* | 1211110 |
| *Juncus sarophorus* | 1000011 |
| *Juncus* sp. | 0010011 |
| *Leptospermum continentale* | 0105000 |
| *Leptospermum lanigerum* | 0000024 |
| *Lilaeopsis polyantha* | 0000011 |
| **Lotus corniculatus* | 1111022 |
| *Luzula meridionalis* | 1111101 |
| *Poa helmsii* | 3200300 |
| *Poa labillardieri* | 1000010 |
| *Ranunculus glabrifolius* | 1000010 |
| *Poa sieberiana* | 0100000 |
| *Poa tenera* | 0201000 |
| **Rubus fruticosus* | 0100201 |

## Group 4. *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland

| | |
|---|---|
| **Anthoxanthum odoratum* | 33210 |
| **Briza minor* | 11000 |
| *Baumea rubiginosa* | 21332 |
| *Blechnum minus* | 01110 |
| *Carex gaudichaudiana* | 11011 |
| *Centella cordifolia* | 10010 |
| **Centaurium erythraea* | 10001 |
| **Cirsium vulgare* | 01001 |
| *Drosera peltata* | 10110 |
| *Eleocharis gracilis* | 23143 |
| *Eriocaulon scariosum* | 10110 |
| *Epilobium gunnianum* | 00100 |
| *Epilobium pallidiflorum* | 01001 |
| *Eucalyptus camphora* | 01000 |
| *Geranium potentilloides* | 00011 |
| *Glyceria australis* | 11001 |
| *Gonocarpus micranthus* | 00110 |
| **Holcus lanatus* | 34323 |
| *Hypericum japonicum* | 10111 |
| **Hypochaeris radicata* | 31111 |
| *Isolepis inundata* | 00110 |
| **Isolepis levynsiana* | 10100 |
| *Isolepis subtilissima* | 00100 |
| **Juncus articulatus* | 00023 |
| **Juncus bufonius* | 00100 |
| *Juncus planifolius* | 31122 |
| *Juncus sarophorus* | 11001 |
| *Leptospermum lanigerum* | 03333 |
| **Lotus corniculatus* | 22111 |
| **Mimulus moschatus* | 10010 |
| *Phragmites australis* | 03014 |
| *Poa helmsii* | 00101 |
| *Schoenus apogon* | 41141 |
| *Schoenus maschalinus* | 31111 |
| **Sonchus asper* | 11011 |
| *Utricularia dichotoma* | 10201 |
| *Triglochin striata* | 20312 |

### Group 5a. *Acacia melanoxylon – Gahnia sieberiana* Open Swamp Forest

| | |
|---|---|
| *Acacia melanoxylon* | 254 |
| *Acaena novae–zelandiae* | 101 |
| **Anthoxanthum odoratum* | 010 |
| *Baeckea utilis* | 100 |
| *Baumea planifolia* | 101 |
| *Baumea rubiginosa* | 100 |
| *Blechnum nudum* | 031 |
| *Carex appressa* | 010 |
| *Cassinia longifolia* | 101 |
| **Cerastium glomeratum* | 011 |
| *Chiloglottis vallida* | 111 |
| **Cirsium vulgare* | 110 |
| *Dichondra repens* | 010 |
| *Eucalyptus camphora* | 400 |
| *Euchiton involucratus* | 010 |
| *Gahnia sieberiana* | 545 |
| *Geranium potentilloides* | 100 |
| *Gonocarpus micranthus* | 100 |
| *Gonocarpus tetragynus* | 101 |
| *Goodenia elongata* | 100 |
| **Gratiola peruviana* | 010 |
| **Holcus lanatus* | 131 |
| *Hydrocotyle* spp. | 111 |
| **Hypochaeris radicata* | 111 |
| *Isotoma fluviatilis* | 110 |
| *Leptospermum continentale* | 100 |
| *Mentha laxiflora* | 100 |
| *Microlaena stipiodes* | 211 |
| *Poa helmsii* | 100 |
| *Poa labillardieri* | 101 |
| *Poa tenera* | 001 |
| *Polystichum proliferum* | 010 |
| *Pteridium esculentum* | 111 |
| **Rubus laciniatus* | 101 |
| **Rubus fruticosus* | 010 |
| *Senecio minimus* | 101 |
| *Schoenus maschalinus* | 010 |

### Group 5b. *Acacia melanoxylon – Eucalyptus camphora* Swamp Woodland

| | |
|---|---|
| *Acacia melanoxylon* | 1 |
| **Anthoxanthum odoratum* | 2 |
| *Blechnum nudum* | 4 |
| *Carex appressa* | 3 |
| *Carex fascicularis* | 2 |
| *Cyperus lucidus* | 1 |
| *Dicksonia antarctica* | 1 |
| *Eucalyptus camphora* | 4 |
| *Gahnia sieberiana* | 1 |
| *Galium australe* | 1 |
| *Geranium potentilloides* | 1 |
| **Holcus lanatus* | 2 |
| *Hydrocotyle hirta* | 1 |
| **Lotus corniculatus* | 1 |
| *Mentha laxiflora* | 1 |
| *Poa helmsii* | 2 |
| *Pteridium esculentum* | 3 |

### Group 5c. *Acacia melanoxylon – Carex appressa* Open Swamp Forest

| | |
|---|---|
| *Acacia melanoxylon* | 0524 |
| *Acaena novae–zelandiae* | 1110 |
| **Acetosella vulgaris* | 0011 |
| **Anthoxanthum odoratum* | 0101 |
| *Baumea rubiginosa* | 1000 |
| *Blechnum minus* | 1011 |
| *Blechnum nudum* | 1301 |
| *Callitriche stagnalis* | 0011 |
| *Carex appressa* | 6777 |
| *Carex fascicularis* | 1000 |
| **Cerastium glomeratum* | 0001 |
| **Cirsium vulgare* | 0111 |
| *Cyperus lucidus* | 0211 |
| *Dicksonia antarctica* | 0130 |
| *Eleocharis gracilis* | 1000 |
| *Epilobium billardieria*num subsp. *billardieria*num | 1000 |
| *Epilobium billardieria*num subsp. *hydrophilum* | 1000 |
| *Eucalyptus camphora* | 0500 |
| *Galium australe* | 0121 |

| | |
|---|---|
| *Geranium potentilloides* | 0011 |
| *Histiopteris incisa* | 0001 |
| **Holcus lanatus* | 3111 |
| **Hypochaeris radicata* | 1011 |
| *Isolepis inundata* | 1010 |
| **Isolepis levynsiana* | 1000 |
| *Isolepis subtilissima* | 1000 |
| *Juncus planifolius* | 1000 |
| *Juncus sarophorus* | 1000 |
| *Juncus sp.* | 1000 |
| *Leptospermum lanigerum* | 2000 |
| **Lotus corniculatus* | 2011 |
| *Mentha laxiflora* | 0100 |
| **Mimulus moschatus* | 0110 |
| *Poa helmsii* | 0100 |
| **Rubus fruticosus* | 1101 |
| *Schoenus maschalinus* | 1000 |
| **Sonchus asper* | 0010 |
| *Stellaria angustifolia* | 0010 |
| **Trifolium repens* | 0010 |

## Group 6. *Eucalyptus camphora – Leptospermum lanigerum* Thicket Swamp Forest

| | |
|---|---|
| *Acacia melanoxylon* | 000120 |
| *Acaena novae–zelandiae* | 111011 |
| **Anthoxanthum odoratum* | 301004 |
| *Baeckea utilis* | 000110 |
| *Baumea rubiginosa* | 220202 |
| *Blechnum minus* | 130111 |
| *Callitriche stagnalis* | 010101 |
| *Carex appressa* | 100010 |
| *Chiloglottis vallida* | 001100 |
| **Cirsium vulgare* | 101011 |
| *Dicksonia antarctica* | 000010 |
| *Eleocharis gracilis* | 201212 |
| *Epilobium billardierianum subsp. hydrophilum* | 100002 |
| *Eucalyptus camphora* | 003350 |
| *Euchiton involucratus* | 001111 |
| *Gahnia sieberiana* | 003450 |
| *Galium australe* | 111011 |
| *Geranium potentilloides* | 001011 |
| *Gleichenia microphylla* | 000230 |
| *Glyceria australis* | 001110 |
| **Glyceria maxima* | 000004 |
| *Gonocarpus micranthus* | 100111 |
| *Histiopteris incisa* | 000110 |
| **Holcus lanatus* | 312311 |
| *Hydrocotyle spp.* | 001101 |
| *Hypericum japonicum* | 000011 |
| **Hypochaeris radicata* | 111111 |
| *Isolepis spp* | 010100 |
| *Isotoma fluviatilis* | 001010 |
| **Juncus articulatus* | 000110 |
| **Juncus bufonius* | 011000 |
| *Juncus planifolius* | 100101 |
| *Leptospermum lanigerum* | 656656 |
| **Lotus corniculatus* | 211311 |
| *Luzula meridionalis* | 000011 |
| *Mentha laxiflora* | 000110 |
| *Microlaena stipiodes* | 001110 |
| *Poa helmsii* | 511000 |
| *Pterostylis falcata* | 001010 |
| **Rubus fruticosus* | 131111 |
| *Sphagnum novozelandicum* | 000100 |

## Group 7a. *Eucalyptus camphora* Swamp Woodland

| | |
|---|---|
| *Eucalyptus camphora* | 44001223205020 |
| *Acacia melanoxylon* | 01000200001110 |
| *Leptospermum continentale* | 02001000111110 |
| *Baeckea utilis* | 12000000000005 |
| *Baumea rubiginosa* | 55766656555565 |
| *Gymnoschoenus sphaerocephalus* | 00000000050000 |
| *Acaena novae–zelandiae* | 01110110001111 |
| *Carex appressa* | 00000201001201 |
| *Carex gaudichaudiana* | 00001000110000 |
| *Gahnia sieberiana* | 03000200000000 |
| *Eleocharis gracilis* | 00210011211010 |
| *Isolepis subtilissima* | 10000301100100 |
| *Juncus planifolius* | 00101101100100 |
| *Juncus sarophorus* | 00000101102010 |
| *Schoenus maschalinus* | 00000100100100 |
| **Anthoxanthum odoratum* | 03111011111131 |

| | |
|---|---|
| *Blechnum minus* | 00220111111100 |
| *Dicksonia antarctica* | 00000200000000 |
| *Phragmites australis* | 00000232024000 |
| **Holcus lanatus* | 11111212221221 |
| *Poa helmsii* | 10122121111020 |
| *Gleichenia microphylla* | 50202000430000 |
| *Sphagnum novozelandicum* | 00007000100010 |
| *Gonocarpus micranthus* | 01111010111011 |
| **Hypochaeris radicata* | 01111111110011 |
| **Lotus corniculatus* | 00011111111111 |
| *Hypericum japonicum* | 00011001110110 |
| *Craspedia paludosa* | 00001000110000 |
| *Eriocaulon scariosum* | 00100000000000 |
| *Epilobium billardierianum* subsp. *billardierianum* | 00001100010100 |
| *Epilobium billardierianum* subsp. *hydrophilum* | 00110000000000 |
| *Epilobium gunnianum* | 00100010100000 |
| *Euchiton involucratus* | 01000000100011 |
| *Galium australe* | 00000111000100 |
| *Geranium potentilloides* | 00000100101010 |
| **Rubus fruticosus* | 00000101001110 |
| *Goodenia elongata* | 01000000110000 |
| *Hydrocotyle spp.* | 01011001110001 |
| *Centella cordifolia* | 01010000100001 |
| *Luzula meridionalis* | 00000010010010 |
| **Mimulus moschatus* | 00000101001100 |

### Group 7B. *Baumea rubiginosa* or *Baumea planifolia* Closed Sedgeland

| | |
|---|---|
| *Acaena novae–zelandiae* | 01100000 |
| **Anthoxanthum odoratum* | 00111142 |
| *Baeckea utilis* | 00003001 |
| *Baumea planifolia* | 00003015 |
| *Baumea rubiginosa* | 77765552 |
| *Blechnum minus* | 00001010 |
| *Carex appressa* | 20010000 |
| *Carex fascicularis* | 00000200 |
| *Craspedia paludosa* | 00000001 |
| *Drosera peltata* | 00000001 |
| *Eleocharis gracilis* | 01101110 |
| *Epilobium billardierianum* subsp. *billardierianum* | 02100001 |
| *Epilobium billardierianum* subsp. *hydrophilum* | 01000000 |
| *Epilobium pallidiflorum* | 10010100 |
| *Gahnia sieberiana* | 00001000 |
| *Galium australe* | 10001000 |
| **Glyceria maxima* | 00000100 |
| *Gonocarpus micranthus* | 00001110 |
| **Gratiola peruviana* | 10000100 |
| *Hemarthria uncinata* | 00000001 |
| **Holcus lanatus* | 13353452 |
| *Hydrocotyle* sp. | 00000010 |
| *Hydrocotyle hirta* | 01000000 |
| *Hypericum japonicum* | 00000010 |
| **Hypochaeris radicata* | 02111110 |
| *Isotoma fluviatilis* | 10000000 |
| **Juncus articulatus* | 00000001 |
| *Juncus planifolius* | 00101000 |
| *Juncus sarophorus* | 01121100 |
| *Leptospermum continentale* | 01000133 |
| *Lilaeopsis polyantha* | 00000100 |
| **Lotus corniculatus* | 11211111 |
| *Luzula meridionalis* | 00000110 |
| *Poa helmsii* | 02013421 |
| *Ranunculus glabrifolius* | 00010100 |
| *Poa sieberiana* | 00000001 |
| *Poa tenera* | 00000001 |
| *Pteridium esculentum* | 02100000 |
| *Sphagnum* sp. | 00001100 |
| *Stellaria angustifolia* | 10010100 |

### Group 8. *Elaeocharis gracilis* Low Sedgeland

| | |
|---|---|
| **Acetosella vulgaris* | 01000 |
| **Anthoxanthum odoratum* | 10110 |
| **Briza minor* | 10010 |
| *Baumea rubiginosa* | 10011 |
| *Carex gaudichaudiana* | 10000 |
| *Dichondra repens* | 00100 |
| *Drosera peltata* | 00120 |
| *Eleocharis gracilis* | 57644 |
| *Eriocaulon scariosum* | 00010 |

| | |
|---|---|
| *Epilobium billardierianum* subsp. *billardierianum* | 00001 |
| *Epilobium billardierianum* subsp. *hydrophilum* | 11010 |
| *Epilobium pallidiflorum* | 10000 |
| *Eucalyptus camphora* | 01000 |
| *Euchiton involucratus* | 11010 |
| *Gonocarpus micranthus* | 00010 |
| *Goodenia elongata* | 00100 |
| *Hemarthria uncinata* | 01100 |
| **Holcus lanatus* | 12222 |
| *Hydrocotyle sibthorpioides* | 30131 |
| **Hypochaeris radicata* | 11110 |
| *Isolepis inundata* | 01101 |
| **Isolepis levynsiana* | 01010 |
| *Isolepis subtilissima* | 32000 |
| *Isotoma fluviatilis* | 10000 |
| **Juncus articulatus* | 10101 |
| *Juncus bufonius* | 01010 |
| *Juncus planifolius* | 11111 |
| *Juncus sarophorus* | 01110 |
| *Juncus* sp. | 02020 |
| *Lilaeopsis polyantha* | 10000 |
| **Lotus corniculatus* | 01033 |
| *Luzula meridionalis* | 10010 |
| *Phragmites australis* | 20000 |
| *Poa helmsii* | 00110 |
| *Schoenus apogon* | 02110 |
| *Schoenus maschalinus* | 01332 |
| *Stellaria angustifolia* | 00212 |
| *Thelymitra* sp. | 00110 |
| *Utricularia dichotoma* | 10000 |

## Group 9. *Eucalyptus camphora – Acacia melanoxylon – Gleichenia microph*ylla Swamp Woodland

| | |
|---|---|
| *Acacia melanoxylon* | 1121 |
| *Acaena novae–zelandiae* | 0111 |
| **Anthoxanthum odoratum* | 1112 |
| *Baumea planifolia* | 2000 |
| *Baumea rubiginosa* | 4111 |
| *Blechnum minus* | 1010 |
| *Blechnum nudum* | 0013 |
| *Callitriche stagnalis* | 0011 |
| *Carex appressa* | 0010 |
| *Centella cordifolia* | 0100 |
| *Dicksonia antarctica* | 0012 |
| *Eleocharis gracilis* | 0122 |
| *Eriocaulon scariosum* | 0100 |
| *Eucalyptus camphora* | 1401 |
| *Euchiton involucratus* | 0011 |
| *Gahnia sieberiana* | 0104 |
| *Gleichenia microphylla* | 7674 |
| *Gonocarpus micranthus* | 1114 |
| *Goodenia elongata* | 0001 |
| **Gratiola peruviana* | 0011 |
| **Holcus lanatus* | 1111 |
| *Hydrocotyle hirta* | 0001 |
| *Hydrocotyle sibthorpioide*s | 0010 |
| *Hypericum japonicum* | 0111 |
| **Hypochaeris radicata* | 1111 |
| *Isolepis inundata* | 0101 |
| *Isolepis subtilissima* | 0111 |
| *Isotoma fluviatilis* | 0001 |
| *Juncus planifolius* | 1111 |
| *Leptospermum lanigerum* | 0224 |
| **Lotus corniculatus* | 0011 |
| *Mentha laxiflora* | 0011 |
| *Pteridium esculentum* | 1111 |
| *Schoenus maschalinus* | 0210 |
| *Utricularia dichotoma* | 0100 |
| *Viola hederacea* | 0110 |

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# Comparing reproductive success in the rare sedge *Gahnia insignis* and the common *Gahnia clarkei* in north-east New South Wales.

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***Abstract:*** Species may become vulnerable because of a reduction of habitat, leading to reduction of population sizes and an increase in geographic isolation between populations, leading to genetic drift that may result in reduced reproductive fitness. The restricted sedge *Gahnia insignis* S.T. Blake (family Cyperaceae), occurring in isolated pockets in north-east New South Wales and Queensland, was compared to a closely related, sympatric, common and widespread *Gahnia clarkei* Benl for flowering phenology and reproductive success. Flowering patterns, examination of pollen, fertilisation and embryo development and seed-ovule ratios show *Gahnia clarkei* has every indication of successful sexual reproduction, but that *Gahnia insignis* appears to reproduce mostly by vegetative means, with an occasional sexual event. This was due to the rarity of pollination opportunities, and to poor pollen viability and pollen quantity, resulting in a much lower seed-ovule ratio than *Gahnia clarkei.* The additional high level of vegetative reproduction in *Gahnia insignis* suggests it may be largely clonal in Nightcap National Park. A genetic study of the whole distribution would add knowledge of the species genetic diversity and differentiation between populations.

Key words: Reproductive success, phenology, disjunct, sympatric

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## Introduction

The population size of many Australian plant species may be reduced through loss of habitat due to clearing, geomorphological processes and climate change. The occurrence of vegetative reproduction or self-fertilisation in a plant species, along with reduced population sizes, can lead to a loss of genetic diversity through an increase in homozygosity (Schemske & Lande 1985) or genetic drift, both resulting in a loss of genetic variation and fitness (Luitjen et al., 1996). This may affect their ability to adapt to changing environments, decrease their levels of reproductive performance and increase their susceptibility to predators (Watson et al., 1994). Small populations may experience poor seed set due to poor pollen quantity and quality (Byers, 1995), and this may contribute to the occurrence of local extinctions.

Measures of reproductive success such as flower morphology and phenology, insect predation, root structure, seed/ovule ratios, seed set, and pollination success at microgametogenesis and megagametogenesis were determined, observed and compared in the rare sedge species *Gahnia insignis* (family Cyperaceae) and the sympatric, more common species *Gahnia clarkei* in 1995. The dioecious flowers of *Gahnia* produce the stigmata first, followed by the stamens approximately one week later. *Gahnia insignis* was found to have little opportunity for pollination, with low viable pollen production and synchronous temporal separation of male and female flowers., resulting in a low fruit set.

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## Materials and methods

*Gahnia insignis* S.T. Blake (Schoeneae: Cyperaceae) is federally listed as rare in Australia (ROTAP code = 3RcaQN, Briggs and Leigh, 1996). It occurs in isolated pockets in Nightcap National Park in northeast NSW, Australia (152° 20'E 28° 35'S). Other disjunct populations include Mt Jerusalem National Park, Comboyne Plateau and Copmanhurst in north-east New South Wales, and in Moreton and North Kennedy districts in Queensland (Blake 1957; NSW Herbarium records). *Gahnia clarkei* Benl also occurs in Nightcap National Park but is a much more common species in eastern Australia, occurring in coastal districts in moist habitat in NSW, Queensland, Victoria, Tasmania and South Australia.

Two populations of each species were observed. *Gahnia clarkei* has a clumping habit for each plant with individuals up to one metre wide and approximately 1.5 metres high; numbers of plants in each population ranged from 100–300 plants. In contrast the root structure in *Gahnia insignis* consists of many widely spreading horizontal roots, any of which may produce upright shoots. It was difficult to determine what comprised an individual plant of *Gahnia insignis,* however one population covered the forest floor for an area of 500 sq. m. while the other colonised the edge of an old logging track for 100 m. *Gahnia insignis* was examined for root structure, with a clump being considered here as an 'individual' plant.

Inflorescences were examined and the number of florets calculated by counting the number of florets per spikelet, spikelets per panicle, panicles per plant, and plants per population for both species. The flowering period, flowering strategies, breeding systems and the seed/ovule ratios (Wiens 1984) were observed. The seed/ovule ratio is the percentage of ovules that develop into seeds/fertile fruits, considered to be approximately 50% in perennials (Wiens 1984). Opportunistic observations on possible insect predators, insects which inhabit the plants, potential pollinators and possible fruit dispersal agents were also included. Inflorescence morphology, seed set (through dissecting fruits), pollen viability, and root structure of the two species were compared.

Destructive sampling for *Gahnia insignis* was used to determine seed/ovule ratios (Wiens 1984), seed set and embryo viability, since there was a high predation rate of spikelets from bud to young fruiting stages, and the pollination rates were low. Plants were tagged at anthesis, then one panicle from three 'plants' from each population was collected every three weeks and fixed in Formalin-Propionic-Alcohol (FPA), and then stored in 70% ethanol before being dissected. The numbers of fruit (and their viability) and the numbers of spikelets from each panicle collected were recorded. *Gahnia insignis* was collected and fixed at three stages of the reproductive process, from one month preceding anthesis to one month following anthesis.

*Gahnia clarkei* had a much shorter flowering period with much higher production levels and larger panicles, so *in-situ* counts were made on the panicles that were tagged at anthesis. *Gahnia clarkei* was collected from two months preceding anthesis.

Material from both species was dehydrated in a series of tertiary butyl alcohol dilutions embedded in paraffin wax, sectioned at 11–12 µm, and stained with safranin and fast green.

## Results

Floral morphology was similar for both species. *Gahnia insignis* had one or two florets per spikelet, while *Gahnia clarkei* always had two. All florets had six anthers and a trifid stigma. However the number of panicles per population was much greater for *Gahnia clarkei* (3812–7769) compared with *Gahnia insignis* (22.5–27.8) (Table 1). The dioecious flowers of *Gahnia* produce the stigmata first, followed by the stamens approximately one week later.

In Nightcap National Park in 1995 flowering in *Gahnia insignis* continued intermittently from early April to late September. Flowering was synchronous within and often between populations, with the presentation of stigma and stamens being temporally separated throughout the whole

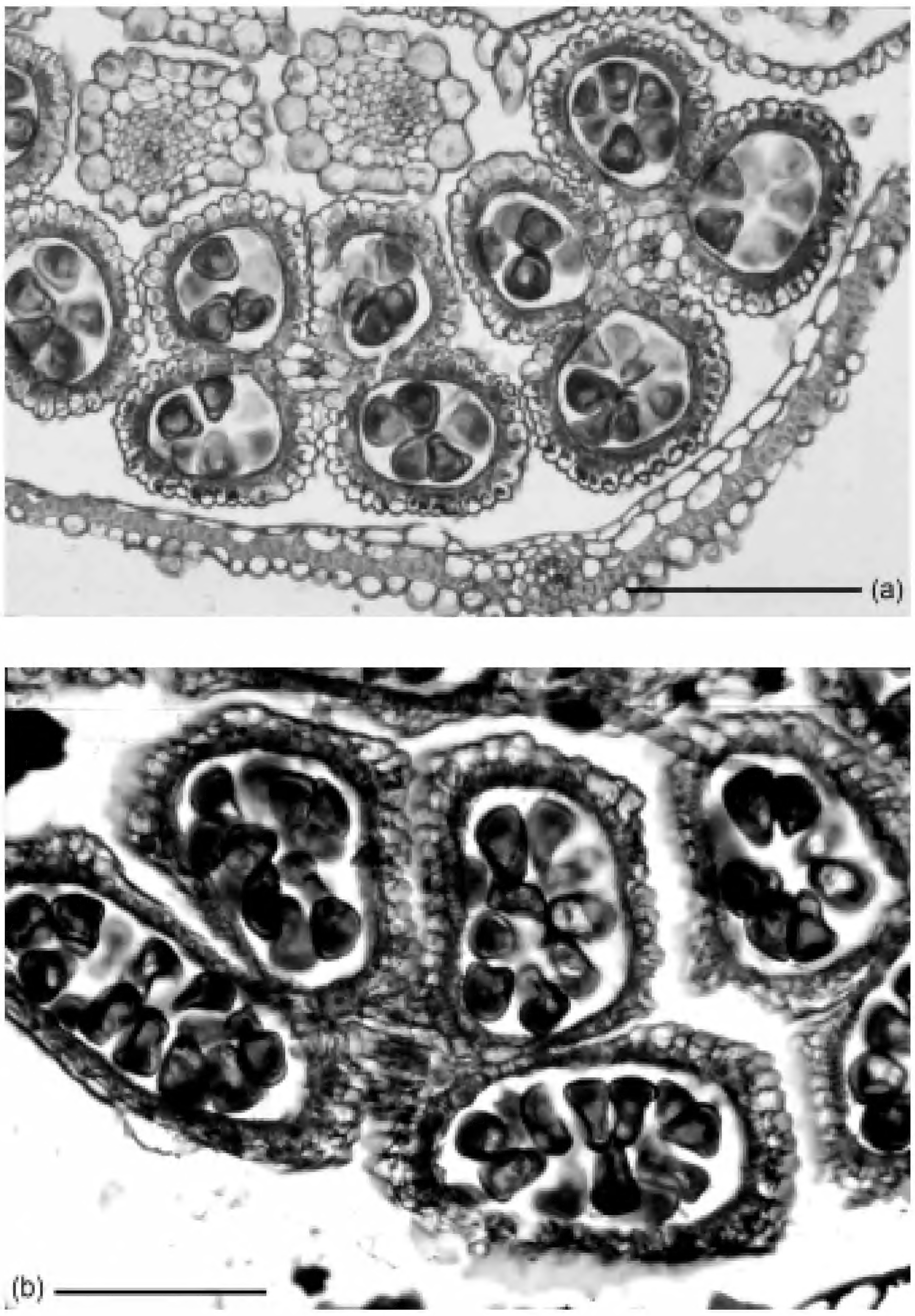

**Fig. 1.** Transverse sections of mature anthers of (a) *Gahnia insignis* and (b) *Gahnia clarkei.* Scale = 25µm.

forest, i.e. in the whole forest you may see only stigmata, or another day you may see only stamens. Thus pollination was impossible most of the time. Plants of *Gahnia insignis* always produced stamens one week after the stigmata appeared, (with the exception of one occasion, presumably very briefly when stamens and stigma were present simultaneously at both sites), suggesting that there is little opportunity for pollination. The stigmata generally last two or three days, and stamens probably similar. Pollen was released but there were only very rarely stigmata present to accept it. Panicles were visible for approximately three weeks prior to anthesis.

Flowering in *Gahnia clarkei* lasted two weeks, with each plant producing flowers simultaneously, but not synchronously with other plants. Pollen was produced in large amounts. Panicles were visible for more than eight months prior to anthesis.

Two stages of microsporogenesis were observed in *Gahnia clarkei*, and four stages in *Gahnia insignis.* The epidermis, middle layer and tapetum are evident in both species, and the endothecium can be seen developing in *Gahnia insignis*. Figure 1 shows transverse sections of anthers with mature pollen grains in *Gahnia clarkei* and almost mature in *Gahnia insignis*, with the spiral endothecium visible. The pollen of *Gahnia insignis* has more unstained pollen grains than *Gahnia clarkei,* which has more grains per anther, larger grains, and more grains which have taken up stain. The unstained pollen grains indicate the presence of cytoplasm and cellulose, and an absence of chromosomes, indicating a lack of viability. Lack of maturity in the *Gahnia insignis* pollen is most unlikely due to the collection regime and the large numbers of samples processed and viewed.

Three stages of megasporogenesis were observed in *Gahnia clarkei,* and four stages in *Gahnia insignis* and appeared to be normal in both species. A tetrad was observed in *Gahnia insignis,* but no embryos were observed in young fruits, suggesting that they may develop late, the fruit was unfertilised or the embryo was aborted. *Gahnia clarkei* showed normal development, with plenty of evidence of fertilisation and normal embryo development, with numerous embryos sighted. This may explain the Seed-ovule ratios results (Table 1) showing *Gahnia insignis* (0.02 and 0.03), has roughly only one tenth of the seed/ovule ratio of *Gahnia clarkei* (0.25 and 0.36).

No insects were observed on *Gahnia clarkei*, but the effects of insect predation on *Gahnia insignis* were obvious even from casual visits. 28% of developing spikelets were attacked by insects, but only 5% of the remaining fruit. Grasshoppers and lepidopteran larvae were observed feeding on *Gahnia insignis.*

## Discussion

The widespread sedge species *Gahnia clarkei* has good outcrossing opportunities, reflected by the evidence of abundant sexual reproduction, and the differences shown in plants within and between populations. Plants showed variation in appearance, the large numbers of flowers produced with abundant pollen produced at varying times, and the large numbers of fruits produced on each plant. Compared to *Gahnia clarkei,* the geographically restricted (within Nightcap National Park) *Gahnia insignis* was found to have little opportunity for pollination due to the temporal separation of the male and female flowering phases throughout the forest and synchronous temporal separation of male and female flowers, reflected in the low seed/ovule ratios (Table 1) and low pollen viability (Figure 1), resulting in a low fruit set.

*Gahnia clarkei* has a clumping habit for each individual plant but the root structure in *Gahnia insignis* consists of many widely spreading horizontal roots, any of which may produce upright shoots. It appears to be reproducing mostly by vegetative means, or occasionally pollinating/fertilising with a closely related individual, resulting in populations that may be largely clonal.

Other largely clonal plant species have also been observed to have low reproductive success, such as some members of the Orchidaceae and Rosaceae families (Gill 1989, Aspinwall & Christian 1992, and Sydes and Calder 1993). While it is possible that *Gahnia insignis* is a relatively new species, the disjunct distribution suggests that the distribution of *Gahnia insignis* was much wider in the past. This hypothesis supported by the presence of a similar species, *Gahnia sclerioides,* growing only in south-west Western Australia (Wilson, 1997). *Gahnia sclerioides* has a similar appearance and habit, grows in a similar habitat, and also has a restricted distribution and abundance, but greater fruit fertility (Wheeler 1996).

**Table 1. Seed/ovule ratios for *Gahnia insignis* and *Gahnia clarkei* populations.**

# Each spikelet of *Gahnia insignis* were assumed to contain 1.5 florets. † = Number of viable fruits per panicle/ Number of florets per panicle.

| Species | Site | Number of spikelets per panicle (+/-s.e.) | Number of resultant fruits containing embryos (+/-s.e.) | Mean % embryo viability | Seed/ovule ratio † |
|---|---|---|---|---|---|
| *Gahnia insignis*# | 1 | 27.8 (3.00) | 2.3 (0.58) | 61 | 0.03 |
| | 2 | 22.5 (2.37) | 1.1 (0.04) | 61 | 0.02 |
| *Gahnia. clarkei* | 1 | 3812 (392) | 2131 (326) | 90 | 0.25 |
| | 2 | 7769 (1590) | 6221 (1109) | 90 | 0.36 |

A low level of viable pollen production and low resistance to insect predation may indicate low genetic variability in *Gahnia insignis* in Nightcap National Park. Testing the genetic variability between populations throughout the whole distribution of the species would provide valuable information for its future conservation, and may point to the possibility of cross-pollinating two or more populations with the aim of increasing genetic diversity and improving the species long-term outlook.

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## References

Aspinwall, N. & Christian, T. (1992) Pollination biology, seed production and population structure in Queen-of the prairie *Filipendula rubra* (Rosaceae) at Botkin fen, Missouri. *American Journal of Botany* 79(5): 488–494.

Blake, S.T. (1957) A new species of *Gahnia* from Eastern Australia. *Proceedings of the Royal Society of Queensland* 68: 37–41.

Briggs, J.D., & Leigh, J.H. (1996) *Rare or threatened Australian Plants,* (CSIRO: Canberra)

Byers, D.L. (1995) Pollen quantity and quality as explanations for low seed set in small populations exemplified by *Eupatorium* (Asteraceae). *American Journal of Botany* 82(8): 1000–1006.

Gill, D.E. (1989) Fruiting failure, pollinator inefficiency and speciation in orchids. *In:* Speciation and its Consequences, (eds Otte, D., & Endler, J.D.), Ch. 19. Sinauer Association Inc., Massachusetts.

Luitjen, S.H., Oodtemeijer, G.B., van Leeuwen, N.C. & den Nus, H.C.M. (1996) Reproductive success and clonal genetic structure of the rare *Arnica montana* (Compositae). *The Netherlands Plant Systematics and Evolution* 201:15–30.

Schemske, D. W. & Lande, R. (1985) The evolution of self-fertilisation and inbreeding depression in plants. II Empirical observations. *Evolution* 39: 41–52.

Sydes, M.A. and Calder, D.M.(1993) Comparative reproductive biology of two sun-orchids; the vulnerable *Thelymitra circumsepta* and the widespread *T. ixioides* (Orchidaceae). *Australian Journal of Botany* 41 (5): 577–589.

Watson, L.E., Uno, G.E., McCarty, N.A. & Kornkven, A.B. (1994) Conservation biology of a rare plant species *Eriocaulon kornickianum* (Eriocaulaceae). *American Journal of Botany* 81(8): 980–986.

Wheeler ,M. (1996) Comparative reproductive biology of some sedges (Schoenae: Cyperaceae). Unpub. thesis. University of New England.

Wiens, D. (1984) Ovule survivorship, brood size, life history, breeding systems, and reproductive success in plants. *Oceologia* 64(1): 47–53.

Wilson, K.L. (1997) New species of Cyperaceae in Western Australia. *Nuytsia* 11: 269–282.

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